Over time the Allies defeated the U-boat threat through a combination of production and technology. Once the US shipbuilding industry was mobilized for war and innovations such as the Liberty ship, built in components around the US and shipped to the coast for assembling, were developed the Allies were building shipping tonnage far faster than the U-boats could sink them. The limitations of anti-submarine technology such as ASDIC (a form of sonar) and depth charges were eventually improved. Anti-submarine aircraft steadily increased their range, reaching far out into the Atlantic to give effective air cover to Allied convoys. By the end of 1943 the Allies were sinking U-boats twice as fast as the Germans could replace them. By the end of the war 75% of all German submariners had been killed.

Technology and war: radar

In the mid-1920s experiments had established that it was possible to measure the distance to an object by timing the return of radio waves bounced off the object. The military applications were soon evident. By the time the war broke out, Britain and Germany had developed radar stations to detect incoming aircraft. Radar's accuracy was refined throughout the Second World War as was the scope of its application. Developments such as the cavity magnetron allowed for the reading of higher frequency radio waves, which proved more accurate. Eventually radar was placed on aircraft to find targets at sea. It was placed on ships to discover surfaced submarines. It was used to aim anti-aircraft guns and find bombing targets through cloud cover.

As with all military technology, each advance in radar prompted the development of countermeasures. Artillery shells that burst in the air releasing fragments of aluminium presented multiple reflective surfaces for the radar to bounce off thus confusing it. Radar detectors mounted on aircraft could alert crews as to when they were being hit with radio waves directing anti-aircraft fire.

Technology and war: anti-submarine warfare

Anti-submarine warfare can be divided into detection/defensive technology and offensive technology. The Allies had discovered the defensive benefits of the convoy system during the First World War. It allowed a comparatively small escort force to protect a greater number of ships. By the end of the war, Allied convoys in the Atlantic grew to over 150 ships. The move by Allied navies toward larger convoys came from the statistical analysis that suggested the number of sinkings in a convoy attack depended on the number of U-boats attacking rather than the size of the convoy, theoretically allowing for larger convoys.

Submarine detection initially relied on ASDIC or sonar developed during the First World War. Although ASDIC was relatively successful in detecting submerged submarines, it could not do so with surfaced U-boats. Escort vessels were eventually equipped with maritime radar sets, which made this easier. Hydrophones were listening devices that could pick up faint sound waves emitted from submerged U-boats. Anti-submarine aircraft used advanced technology such as magnetic anomaly detectors that could detect the change in magnetic fields caused by a submarine hull to find their prey.

Once detected, escort vessels would launch an attack on the submerged U-boat. The primary weapon used by the Allied navies was the depth charge, a waterproof explosive charge detonated by a pressure fuse. Early in the war depth charges were dropped off the stern of ships or thrown by single charge launchers, requiring the attacking ship to pass over the submarine several times in order to either sink it or force it to the surface. The Hedgehog was an improvement in that it fired 24 projectiles 80 metres ahead of the ship and detonated on contact. This meant that the U-boat had far less time to escape once its own hydrophone heard the approaching ship.

Long-range aircraft, which could spot and attack U-boats, were highly effective in protecting convoys. As the war progressed the range of aircraft such as the Sunderland Flying Boat and the PBY Catalina increased, as did their ability to attack U-boats. Devices such as the absolute altimeter meant that aircraft could fly at far lower altitudes with safety, increasing the accuracy of their attacks.

The air war

Battle of Britain

When France surrendered to Germany in June 1940, the German high command expected Britain to ask for terms of peace. Churchill, now the Prime Minister, would hear none of this. To say that Britain was alone does a disservice to Canada, Australia and New Zealand who stood by her. Nevertheless, the fact that Britain would not negotiate meant that a military solution to her resistance would have to be found. That solution became known as Operation Sealion.

Sealion planned Germany's amphibious invasion of Britain. To call it a plan is generous; Sealion lacked the meticulous planning that Germany's other operations had entailed. Even had it been given the attention required, Germany did not have the naval resources to control the channel long enough to get an invasion force across. Hitler and Goering did, however, believe that they had the resources to control the airspace over the islands and the channel, also a prerequisite to invasion. The Luftwaffe was given the mammoth task of destroying Britain's coastal defences, eliminating the RAF's ability to operate, and preventing the ability of ground forces to operate once the invasion was underway. This attempt would become the Battle of Britain.

From the beginning the RAF enjoyed certain advantages over the Luftwaffe.

- British radar installations could detect incoming aircraft.
- The Luftwaffe had suffered greater losses in the Battle of France than the RAF.
- The British Spitfire, though fewer in number than the Hurricane, was equal, if not superior, to the German Bf 109 Messerschmitt.
- The Hurricane, although an inferior fighter, could be produced in large numbers quickly. In all the British outproduced the Germans in fighter aircraft at a rate of 25:7.
- As much of the aerial combat took place over or close to Britain, salvage of damaged aircraft and recovery of pilots was easier than it was for the Luftwaffe.
- Germany had no heavy bombers suited to destroying large urban centres or industrial facilities. The Luftwaffe would rely on medium-sized level flight bombers designed to support ground forces – the "flying artillery" of *Blitzkrieg*.

Class discussion

To what extent should merchant marine sailors (civilian sailors who crewed the cargo and tanker ships) be entitled to the same benefits and honours as sailors in the navy?

▲ German Bf 109 Messerschmitts over England in 1940. How did rearming after Germany give Britain a technological advantage?

▲ An RAF Spitfire. What was the relationship between quality and quantity in British aircraft production?

- Because the Luftwaffe was operating far from its bases in France, the amount of time her fighters could stay over the target area to protect her bomber fleets was limited to 15 minutes, leaving these aircraft unprotected for a portion of each operation.
- British Intelligence could decipher Luftwaffe radio transmissions.

The Germans first attempted to eliminate the coastal radar installations during July and early August. Although achieving some success, they abandoned this part of the operation before it was complete, leaving the important early warning system functional throughout the battle. The exchange rate during this part of the battle was telling. The Germans lost 180 aircraft and the British lost 70.

On 13 August the Luftwaffe began to attack RAF airfields, sea ports and other strategic targets. This pattern would continue through to 7 September, and although German losses were always greater than British losses in terms of total aircraft, it was unclear how long the RAF could continue to resist the onslaught against its airfields. It was beginning to lose fighters faster than they were producing them. On 7 September Hitler ordered the focus of attack to shift to London in an effort to break British morale and bomb them to the conference table. Shifting the attacks to London allowed the RAF to recover and rebuild, but it also placed the burden of the battle on the shoulders of the citizens of London. It pushed the RAF hard and on 15 September it committed all its reserves to repulsing a massive raid against the capital. The attack was met and defeated. Daylight bombing raids continued into October, causing damage that was far outweighed by the cost to the Luftwaffe. Germany's air war against Britain would now focus on a terror bombing campaign of urban centres.

Class discussion

These weapons were in part designed to spread terror as well as destruction. How effective is terror bombing as a strategy? To what extent does its effectiveness depend on whether the target country is a liberal democracy or a dictatorship?

Technology and war: pilotless weapons

The Germans had been working on pilotless aircraft, specifically rocket technology, throughout the 1930s. By the end of the decade the programme had grown to the point where a permanent test facility was developed, however, it was not until 1942 that a rocket was successfully tested. The test facility was severely damaged in an air raid in 1943, further delaying the deployment of an operational weapon.

V1 bombs were flying bombs that carried about 900 kg of explosives, could travel about 300 km, and were powered by a jet engine. They could be launched from aircraft or from the ground. Once the preset distance had been covered, the engine would stop and the bomb would fall out of the sky. This meant that it was not a very accurate weapon. The Luftwaffe fired 8,500 V1s, about half of which were destroyed before they landed.

The V2 was a ballistic missile that carried the same explosive power as the V1, but because it was propelled by a rocket, it could travel six times faster than the V1 and was thus more difficult to defend against. About 1,300 V2s landed in London, their primary target, killing 2,400 civilians and wounding many more.

The Blitz

The Blitz refers to the sustained bombing on urban centres and industrial targets between September 1940 and May 1941. German goals throughout the Blitz were twofold. The first goal was to crush civilian morale such that Churchill and his government would have to negotiate an end to the war. Failing that, the raids were designed to impede British war production. On both counts, the campaign was a failure, but at a terrible cost.

The fate of Warsaw had given ample warning to British civilians of what high explosive aerial bombing could do. From September 1939 civil defence authorities in Britain began to make preparations. Many types and sizes of shelters were built or adapted from existing structures, sometimes without direction from the government, the most famous being the London underground. A fear that the enemy might use aerial bombs filled with poison gas prompted authorities to issue as many gas masks as they could. Blackout regulations were enforced in an attempt to make finding targets more difficult.

For eight months the campaign was unrelenting. At one point London endured 57 consecutive nights of bombing. British propagandists turned the suffering into a rallying point. Churchill made a point of being seen out surveying damage and talking to victims. The royal family even toured bombing sites. More than 40 000 civilians were killed during the Blitz.

Strategic bombing

Strategic bombing refers to the aerial bombing of targets of strategic importance to the enemy's war effort. In general, this fell into two categories. Area bombing was the indiscriminant bombing of all the structures in an area, regardless of strategic value. Precision bombing was designed to limit the damage, and thereby concentrate it, on smaller target areas such as industrial sectors, railway lines and ports.

The Luftwaffe, designed to support ground force action, never developed the machines to carry out heavy bombing deep into enemy territory. They would never have this ability, although their night fighters initially inflicted heavy losses on British Bomber Command.

Technology and war: long-range bombers

When the German Luftwaffe switched from attacking radar installations and airfields during the Battle of Britain it did so without the basic requirement of strategic bombing: long-range, level flight heavy bombers. The Allies, being more committed to long-range strategic bombing, devoted more resources into developing models capable of delivering large payloads of explosives to Germany's industrial heartland, delivered by the British RAF and the US Army Air Corps by night.

The British hit upon its most durable design in 1942 with the mass production of the Avro Lancaster. Its range was 4,000 km and was manned by a crew of seven. Its bomb capacity was 14 standard 1,000 lb bombs. It was very versatile in terms of possible payloads with a bomb bay that could be easily converted to carry a wide range of ordinance, including the "bouncing bombs" of the Dam Raids and the 22 000 lb. "Grand Slam". Navigational aids such as the "Gee" system and later "Oboe" allowed for precise navigating at night, essential for the British bombing strategy.

The Boeing Corporation designed a series of very effective long-range bombers for US forces in both Europe and the Pacific. Initially developed in 1937, the B17 was used in large numbers in both theatres, with a number of models produced by a variety of companies. Eventually over 12 000 B17s were produced. Nicknamed the Flying Fortress, the B17 had a range of 3,000 km and could carry between 2,000 kg and 3,600 kg of bombs depending on distance to target. Equipped with the precise Norden bombsight, the B17 dropped approximately 40% of all aerial bombs dropped by the US during the war. The B24 Liberator was designed to replace the B17 and was produced in greater numbers than any other bomber in the war. The B17 was still preferable to aircrew and the B24 augmented rather than replaced the B17 even though it carried a larger payload. The B29 Superfortress only saw action in the Pacific. Its range, ceiling, speed and ordinance all made it the most advanced long-range bomber when it first flew.

The Allied strategic bombing campaign made use of many types and sizes of bombs. The type of target generally determined the type of bomb used. All-purpose demolition bombs ranged in size from 45 to 1,350 kg and were used against industrial targets, railroads and cities. Fragmentation bombs were generally used against ground troops and defences. Incendiary bombs were designed to start fires and were used against cities in both European and Pacific theatres.

Class discussion

Is there an ethical difference between fire-bombing cities with incendiary bombs and demolition bombing cities with high explosive bombs?

▲ A B17 Flying Fortress. What role did strategic bombing play in the Allied victory?

British operational doctrine advocated night bombing missions deep into enemy territory. The cover of night was partially to overcome the fact that the British had no long-distance fighters that could offer protection to its bomber fleets. As the size, number and range of Bomber Command's aircraft increased, it was able to inflict ever-greater damage on German cities in area bombing missions. For example in May 1942, 1,000 British bombers attacked the German city of Cologne,

setting 600 acres of the city ablaze. This highlighted a new tactic of the commander of Bomber Command, Arthur "Bomber" Harris. Incendiary bombs would be salted in among high explosive bombs to ensure that what was not blasted would be burned.

TOK discussion

For each of the following targets write arguments for and against attacking it with aerial bombs during a time of war. In groups of three or four discuss your arguments and make the decision whether or not the target should be bombed.

- Ball bearing factories
- Munitions factories
- Ports
- Cities
- Railroads

1 On what basis did you make the arguments for and against aerial bombing? What were the most important factors in coming to a decision?

2 To what extent did your decision differ from the decision made during the Second World War? How do you account for any difference?

Bomber production

Bomber	Country	Number produced
B17 Flying Fortress	USA	12 730
B29 Superfortress	USA	3970
Avro Lancaster	Britain	7377
Dornier Do 217	Germany	1900
Heinkel He 111	Germany	6400
Junker Ju 88	Germany	15 000

The arrival of the United States Eighth Air Force in 1942 brought a different approach to strategic bombing. The US bombers were fitted with an excellent daylight bombsight that allowed for more targeting precision. These B17s were heavily armed so that they could fight their way deep into enemy airspace, drop their payloads and fight their way out without fighter protection. This proved disastrous and the Eighth Air Force would limit its deep missions until long-range fighter escorts were available. The US daylight precision bombing was seen as complementing the British night-time area bombing, but its lack of protection limited it to attacking targets in France, Belgium and the Netherlands. By 1944 the United States Army Air Force (USAAF) was equipped with the excellent P-51 Mustang fighter which could operate far into Germany and outmatched any Luftwaffe fighter.