The year 1940 was a critical one in the development of fuel tank protection and other safety features for combat aircraft. The European war started in September 1939; and, in late 1939 relatively few combat aircraft in Europe or elsewhere were equipped with protected fuel tanks or armor plate to protect the pilot, aircrew or vital equipment. The main exception was the German medium bomber force where self-sealing fuel tanks were standard. In the United States none of the principal combat aircraft of the Army Air Corps (B-18, A-17, P-35 and P-36) had armor or fuel tank protection. The same was true of U.S. Navy aircraft. By the end of 1940 most aircraft in Europe flying in combat had some form of fuel tank protection and armor. In the United States research and development in fuel tank protection resulted in rapid advances and important improvements in self-sealing fuel tanks.

Fuel tank protection was particularly a problem since armor plating the entire system of fuel tanks and lines was simply impracticable. The earliest attempt to bullet-proof a fuel tank may have been the Loughead redesign of the Curtiss HS-2L flying boat in 1918. The idea of creating a fuel tank or coating a tank in a way that would seal bullet holes reappeared periodically but its practical implementation proved difficult. Vulcanized rubber had been used to coat the interior of steel tanks in various industrial applications. Vulcanized rubber (natural rubber heated in the presence of sulfur) was insoluble in most common solvents including gasoline. In contrast natural rubber was soluble and expanded in the presence of gasoline. These properties were known and had been utilized to make flexible vulcanized rubber hoses to replace metal piping in aircraft fuel and oil lines. They made rubber a potential candidate for application in protected fuel tanks. Eventually combinations of synthetic rubber-like materials and natural rubber proved most effective.

In Germany chemical engineering related to rubber and synthetic rubber-like materials was relatively advanced. The Germans exploited the idea of combining layers of rubber to produce a protected fuel tank. Early examples of this technology were fitted to the Ju 86 and Do 17.
bombers in production in 1937 and 1938. These first examples were more expensive than simple aluminum tanks and were relatively heavy. Later these tanks would prove effective against rifle caliber fire in actual combat. By 1939 a standard German medium bomber tank consisted of chrome-tanned leather 3mm thick, a 3mm absorbent strata of unvulcanized rubber, and 0.5mm of vulcanized rubber. It was both lighter and more effective than earlier tanks.

A number of countries were engaged in experiments with protective features for bombers and to a lesser extent for fighters. In addition some countries such as Germany were actually fitting protected fuel tanks to aircraft on the production line. In 1939 when the Japanese army upgraded its Type 97 heavy bombers (model Ki 21-Ib) with added armament it also added a basic form of fuel tank protection, thin layers of laminated rubber covering the standard fuel tanks. This might be the exception that proves the rule since this was prior to similar American or British bombers having any type of fuel tank protection.

The Soviets were notable in providing pilot and fuel tank protection for fighters earlier than other countries. First introduced in 1934, later versions of the Polikarpov I-15, beginning in 1936, were equipped with a 9mm thick steel alloy plate protecting the pilot's head. Late model I-15's and the monoplane I-16 were fitted with a system of piping that captured engine exhaust gases, cooled them, and introduced them into the fuel tank to reduce the oxygen content of the vapor left in the tank as fuel was consumed. By the time the Russians fought the Japanese over Nomonhan in 1939 some of their fighters were equipped with the exhaust gas system. The basic concept of controlling the volatility of the gaseous contents of the fuel tank remains relevant today. Neither the pilot nor fuel tank was completely protected but these early efforts to introduce protective measures in a fighter design were in advance of other countries. Some later Soviet fighters notably the widely used LaGG-3 were similarly equipped but added fuel tanks encased in fabric sheets impregnated with phenol-formaldehyde resin derived from the original
Safer Flying

Fire Risk Greatly Reduced by Henderson Crash-proof Tank

A phrase which occurs with distressing frequency in accounts of air crashes is "the machine caught fire and all the occupants were burned." Granted that in a number of cases the crash was so serious that the occupants would have been killed anyway, there must be very many others which were not in themselves so serious that loss of life would have resulted had it not been for the fire.

During the war when risks were inevitable, many precautions were taken against fuel fires and leakage. In particular self-sealing tanks, automatic chemical extinguishers and supplies to the tanks of nitrogen under pressure were provided. Now that civil aviation is about to be revived, although such elaborate precautions may not be practicable, it is surely time that serious attention was given to the possibility of reducing the danger of fire in a crash. Apart from the risk to the occupants themselves, there have been many instances of machines hitting people or houses on the ground, and this aspect should not be overlooked.

There has been in existence for several years a type of fuel tank which has been found to give a very substantial measure of protection against fire in crashes which would not otherwise prove fatal to the crew. It is the Henderson crash-proof tank, designed and manufactured by the Henderson Safety Tank Co., Ltd., of Elstree Way, Elstree, Herts.

Sandwich Construction

Basically the Henderson tank is a sandwich shell composed of an inner shell of welded construction, an outer shell with folded-seam joints, and a layer of "Hencorite" rubber between the two shells. This construction by itself provides a good degree of protection against rupture in a crash, but it is the combination of the sandwich type of shell with a special method of attaching the internal baffles which makes the tank so effective.

Details of the baffle attachment are shown in a sketch. Stiffeners of I-section are spot-welded to the inner tank shell. The baffles are slotted to receive the special baffle tabs, the lower ends of which are spot-welded to the stiffeners while the upper ends slide in the baffle slots. For normal flying, the spot-weld attachments are sufficient to hold the baffles in place, but in a crash they give way, the tabs pull out of their slots and the baffles come clean away from the main shell, which becomes in effect a "bag" free to deform. The complete absence of riveting prevents the shell from tearing or bursting.

A great number of these tanks have been fitted to Miles Masters and examination of several following crashes showed that although the tanks had been damaged, no leakage had occurred even under circumstances that would have caused a standard tank to burst and in none of these instances had fire broken out. An additional advantage of this type of construction is that maintenance is reduced to practically nothing, since the "Hencorite" takes care of all the minor repairs.

(A Concluded at foot of p. 122.)
Crashproof Fuel Tanks for Safer Flying

In protecting the lives of our future pilots from the constant fear of fire in the air or after a crash, the Henderson Crash-Proof fuel tanks are now fitted as standard equipment in the world's fastest training machine... the Miles Master.
Exploding Fuel Tanks

THE INDUSTRY

Henderson Safety Tank

Fire in the air or as the result of a crash, perhaps quite minor in itself, has, since the commencement of flying, been one of the most prolific causes of disaster and one of the major problems to be solved. It was in an attempt to eliminate this bugbear that Henderson Security Tank Co. Ltd., of Elstree Way, Elstree, Herts, embarked on a programme of research and development over nine years ago. The attempt has been very successful. So much so that the Air Ministry has insisted that all the Miles Master advanced trainers now in production are to be fitted with Henderson security tanks further to reduce the already low figure of training fatalities.

In practically every air crash petrol tanks burn on impact, and shower highly inflammable fuel over hot engines and exhaust pipes. There are, of course, several causes of crash fires, such as short circuits in the electrical equipment, sparks struck from the ground or static discharge, but in many cases fire results from ignited engine oil, grease or loose petrol or petrol vapour. For this reason it is clear that if fuel tanks can be so constructed as to withstand impact and distortion without bursting in the event of a crash, then the risk of a major configuration is reduced to a minimum.

The walls of the Henderson tank are built up in three layers to a total thickness of 0.01 in. and each layer is a complete leak-proof unit in itself. Both the inner and outer shells are of thin sheet copper sandwiching between them a continuous film of Henron-a pattern rubber product—which is vulcanised to both the metal casings. In effect, the tank is a flexible bag which is stabilised in all directions by the inner and outer shells. The baffles attached to the inner walls of the tank are secured by a self-releasing device by which they become detached in the event of a crash, thereby enabling the pressure inside the tank to be evened up. Furthermore, as the tanks are fashioned without any rivets or welds, a Henderson security tank is definitely proof against leakage and seepage, a common source of trouble in present-day tanks. The Henderson Safety Tank can be built to any shape and has been designed to take any required stress or strain. In spite of the tank's triple skin its weight is unexpectedly low-between 1 to 1.5 lb. per gallon for capacities of 50 gallons and upwards, which is little more than that for tanks employed on modern commercial aircraft.

War is only a temporary condition, and, very wisely, the Henderson Company have concentrated on the crash-proof problem, but it is gratifying to find that this self-same tank has excellent bullet-proof qualities as well. So far as their works a tank which was shot through and through some two months ago and yet shows no sign of a leak—not even a weep. The particular form of construction lends itself to very easy repair of bullet-holes; in fact, anyone who can handle a screwing iron with some skill is capable of carrying out the work. This is a very distinct advantage in the field where every hour a machine is out of commission is of profit to the enemy.

A New Fuel Gauge

Waymouth Gauges and Instruments, Ltd., have designed a fuel gauge serving the principle of measuring the specific inductive capacity of the petrol in the tank.

Two plates, one of which may be the usual baffle, between 0.01 in. and 0.025 in. apart and insulated from one another, are fitted vertically inside the tank, the plane of the plates being in the direction of flight. These two plates become an electrical condenser the capacity of which varies according to the area of the plates immersed in the fuel. The dashboard instrument is a direct reading electrical capacity meter.

Suitable design of the condenser plates and the use of a switch incorporated in the dashboard instrument, enables the contents of tanks of dissimilar size and shape and containing either petrol or oil to be shown on the same scale. As many as six tanks may be controlled by a single instrument. Current consumption is 0.1 amp at 24 volts pressure, but as low as 20 volts or as high as 35 volts can be employed without appreciably affecting the reading. There is no direct electrical connection between the tank and the electric supply—it is via a condenser—therefore there is no possibility of fire being caused by sparking; only about 1,000 volt is used in the tank.

In Britain Overseas Airways are equipping one of their DH86s with this gauge for trial on regular service, and it is hoped that official approval by the Air Registration Board will be given shortly.

The address of the company is 31, Brunel Road, Old Oak Common Lane, Acton, W.3.

NEW TITLES FOR THREE I.C.I. COMPANIES

The British Dyestuffs Corporation Ltd. will in future be known as I.C.I. (Dyestuffs), Ltd., Nobel Chemical Firms, Ltd., as I.C.I. (Paints), Ltd., and the Salt Union, Ltd., as I.C.I. (Salt), Ltd. This decision will bring the three associated companies into line with the other manufacturing sections of Imperial Chemical Industries, Ltd.

The British Dyestuffs Corporation, Ltd., has been an associated company of Imperial Chemical Industries since the formation of the combine in 1926. Its up-to-date laboratories at Blackley, Manchester, have done much to make Great Britain independent of imported dyestuffs. The research covers not only dyes, but rubber and medicinal chemicals, pest control, laundry and textile products.

Nobel Chemical Firms, Ltd., of Wrexham Road, Shrewsbury, was one of the constituent companies of Imperial Chemical Industries. This company has developed the use of nitro-cellulose and synthetic paints.

The Salt Union, Ltd., of Liverpool, 2, is the youngest of the I.C.I. groups. When formed in 1860 it consisted of eight salt works and is now the largest salt-producing company in Great Britain. It was purchased by Imperial Chemical Industries, Ltd., in 1927.

CHANGE OF NAME

Imperial Airways (Australasia), Ltd., formerly Imperial Airways (South Africa), Ltd., Airways House, W.1, London, S.W.1,-Name changed to Imperial Airways, Ltd., on April 15, 1929. At March 22, 1930, Imperial Airways, Ltd., held 99,079 shares of £1 out of 200,000 issued.

Imperial Airways House, W.1,—Name changed to Airways (Atlantic), Ltd. on April 14, 1930, Imperial Airways, Ltd., held 99,079 shares of £1 out of 200,000 issued.

Imperial Airways, Ltd., previously Imperial Airways (Bermuda), Ltd., Airways House, W.1,—Name changed to Imperial Airways (Bermuda), Ltd., on April 14, 1930. At March 22, 1930, Imperial Airways, Ltd., held 99,079 shares of £1 out of 200,000 issued.

C. F. Aircraft, Ltd., 25, Bishop Lane, E.C.1,—Name changed to Fane Aircraft Co., Ltd., on April 15, 1929.
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synthetic resin, Bakelite (sometimes called “hard rubber”) to the exhaust gas system and armor. In 1939 a prototype Yakovlev fighter had its metal fuel tanks encased in vulcanized rubber. Later LaGG-3’s also adopted the rubber encased tanks.

During the Spanish Civil War (1936-1939) foreign military observers reported on the armor protection of Soviet fighters supplied to the Republican forces. United States Navy and Army Air Corps technical offices received these reports. Reports of the exhaust gas system came later during the fighting in the Far East and were forwarded via diplomatic channels to the U.S. Army and Navy. For the Germans tracer and incendiary rounds fired from Soviet Polikarpov fighters at their Ju-52’s used as bombers with unprotected fuel tanks may have spurred developments. The Ju-86 bomber was one of the first German aircraft to have tanks with rudimentary bullet protection.

France purchased a considerable number of American combat aircraft before and in the early months of the war. The export version of the Curtiss P-36 which they acquired in quantity was well thought of but came in for some criticism once combat began for its lack of armor and protected fuel tanks. This criticism would have been more fairly leveled against a lack of capability to retrofit the P-36 with protective features. At the war’s start few French aircraft were well equipped with protective features and their most numerous fighter, the Morane-Saulnier M.S. 406 did not have a protected fuel tank but was hastily fitted with pilot seat armor after lack of this was recognized as a serious deficiency. Their most modern fighter the Dewoitine D-520 originally came off the production line with pilot armor but lacking protection for its fuel tanks. Another American import the newly designed Douglas DB-7 light bomber was initially delivered without armor or tank protection but the French later required these to be added on the production line.

In Britain research on protected fuel tanks reached the stage of practical application in 1939. Henderson Safety Tank Co. Ltd. built a tank in three layers 3/16th inch thick consisting of a metal wall, a sealing sheet of “hencorite” rubber, and another layer of metal. Fireproof Tanks Ltd. took another approach by applying a resilient covering to the outside of a standard aluminum fuel tank. The Henderson product was meant to be crash proof as well as bullet protected and it found applications in training aircraft in addition to combat aircraft, mainly bombers. The covered tank was initially applied to the Fairey Battle light bomber whose mission included low level attacks. It was subsequently fitted to fighters and a variety of other aircraft. Additional firms were eventually involved in producing various types of protective covers for tanks among them Dunlop a leading tire and rubber company. The fact that these protective technologies were available did not mean that they were immediately applied or considered a matter of high priority.

Things were changing rapidly. In May 1940 Winston Churchill wrote to President Franklin Roosevelt: “Our most vital need is, therefore, the delivery at the earliest possible date of the largest possible number of Curtiss P-40 fighters, now in the course of delivery to your Army.” The first P-40 arrived in Britain in September 1940 during the Battle of Britain. About 140 early model P-40s were delivered to Britain without protected fuel tanks or armor. None was ever used in combat despite the fact that below 20,000 feet the P-40 was in many respects superior to the most numerous R.A.F. fighter, the Hurricane I; and, could compete favorably with both the Hurricane and Spitfire in low altitude performance and range.

In 1940 after several months of combat, Britain’s Royal Air Force began to retrofit its fighters and bombers with armor and fuel tank protection. This was done even though the weight of armor adversely affected climb rate and range, and, in the case of the Spitfire, merely adding an externally mounted bullet-resistant glass windshield reduced maximum speed by more than 5 m.p.h. Armor added 73 pounds to the Spitfire’s weight. The standard
On August 24, 1940 the Bf 109E-4 flown by Fw. Artur Beese of 9./JG 26 was shot up by R.A.F. fighters. Beese crash landed his “Yellow 11” near St. Ingelvert, France.

Beese survived the crash. He owed his life to his head armor that stopped a bullet that entered the cockpit from behind.
of safety sought by the Royal Air Force for fighters was protection from .303 caliber fire at 200 yards in a cone of 20 degrees from directly astern or directly ahead.

The Spitfires of No. 92 Squadron were just being equipped with the new windshield when the squadron first entered combat in late May 1940. Stanford Tuck soon to become squadron leader and a great ace confronted a Bf 109 in a head on pass and survived two bullet hits in his windshield. Later a third bullet from the ground dinged the armored windshield. Tuck’s Spitfire had been fitted with the armored windshield that very day. Other Spitfires in the squadron had not yet received the new feature. In its first day of combat 92 Squadron lost half its strength including its squadron commander. The following day Tuck shot down two Do 17s. One fell in flames after a prolonged hammering and the other crashed without burning. Tuck returned in his badly damaged Spitfire with minor wounds inflicted by a Do 17 gunner. One Spitfire was lost and others damaged by the German gunners in this combat. In future combats Tuck would badly riddle a Do 17 which none-the-less survived and he would return with damage from a Do 17’s gunner.

In June 1940 No. 92 Squadron received armor plate behind the pilot seats of its Spitfires as did a number of other Spitfire and Hurricane squadrons. Almost immediately reports were received of pilots being saved by their armor. Not all squadrons were immediately equipped. In some squadrons armor arrived but days passed before fittings to mount the armor were received.

Fuel tank protection for R.A.F. fighters was initially obtained by wrapping the tank with “Linatex”, a blanket of rubber and treated canvas (the rubber expanded when exposed to gasoline and filled a hole caused by a bullet puncture). Linatex had originally been developed for industrial and various aviation applications and while not a perfect solution was readily available. Hurricane tanks were retrofitted with Linatex
coverings by squadron maintenance personnel beginning in September 1940. Spitfires had a modicum of protection provided by heavy gauge aluminum on their cowlings over their upper fuel tanks. Their tanks were also sandwiched between two sturdy aluminum bulkheads. Spitfires coming off the production line and out of repair facilities at the end of September were fitted with Linatex fuel tank coverings. Like the Hurricanes Spitfires were also refitted in the squadrons as other maintenance work permitted. Although not acknowledged at the time this was less than completely satisfactory. Since these were retrofits there was not sufficient clearance to fit the material to all tanks. In particular the Spitfire’s upper fuel tank in front of the cockpit was left uncovered. Pilots that encountered fires in this tank usually suffered disfiguring facial burns if they survived. The reserve fuel tank directly in front of the pilot on the Hurricane was also left uncovered because it was thought armor and the engine were sufficient protection. Although covered with Linatex the Hurricanes’ main wing fuel tanks gained a reputation as being far from invulnerable.

The covered tanks were fitted to various aircraft in addition to Spitfires and Hurricanes. The Germans found examples on a number of crashed aircraft in 1940 and 1941. The coverings they examined had multiple layers of protective material and varied from 5 to 15mm (about 2/10 to 6/10th inch) in thickness. When the material was tested in the United States it was found to be useless against .50 caliber fire. Some American experts thought Linatex might be somewhat effective against rifle caliber fire but suspected it was fitted more as a morale factor pending the development of more satisfactory tank protection.

American conclusions may have been unduly pessimistic since in combat bullets were normally fired at longer ranges than in the test laboratory and had to penetrate the outer skin of the wing or fuselage before impacting a fuel tank. The velocity and energy of the bullet would be somewhat reduced by the encounter with the aircraft’s skin (a low angle of incidence potentially deflecting the bullet) and this may have increased the survivability of the tank when hit. However, the encounter of the bullet with the skin usually caused the bullet to tumble sometimes resulting in the bullet impacting the tank along its long axis rather than its narrowest profile. A tumbling bullet that retained enough velocity to penetrate the tank could create a large hole that would be difficult to seal.

An external tank covering was fitted to some aircraft produced in the United States for the British. The Curtiss Tomahawk II (equivalent to U.S. P-40B model) was fitted with this type tank protection (the material was “Superflexit” previously used in aircraft hose and piping applications). The aircraft that were supplied to the American Volunteer Group (Flying Tigers) in China were so equipped. The experience of the Flying Tigers seems to confirm the efficacy of Superflexit or Linatex-type protection against light caliber machine guns. Tomahawks were often hit by Japanese machine gun fire but comparatively few became outright losses in combat and rare were reports of Tomahawks crashing in flames. Most of their opponents whether bombers or fighters mounted only rifle caliber machine guns.

When the Battle of Britain began in July of 1940 the Royal Air Force was still in the process of equipping some of its Spitfires and Hurricanes with armor. Protected tanks were not standard until well into the battle. A Messerschmitt Bf 109E-3 captured early in the war was not equipped with armor or a self-sealing fuel tank. However, the Bf 109E-4 and later production Bf 109E-3s were equipped with pilot armor and many early production Bf 109E-1s and E-3s were retrofitted with armor before the Battle of Britain. This consisted of two 8mm thick bolt on armor plates, a head protection plate of about 29 pounds and a back plate of 53 pounds. The 8mm plates proved capable of defeating British .303 rounds. Some pilots objected to having the armor added to their aircraft preferring to forego the protection and save the added weight.

By July 1940 some of the Bf 109Es operating over Britain had armored glass windshields as
Covered tanks were common knowledge even to the Germans. In addition to Linatex by 1941 six other types of covers had been approved by the British Air Ministry.
Richard L. Dunn

well as pilot armor. The Bf 109E had a laminated bulkhead behind the fuel tank but self-sealing fuel tanks first appeared on the Bf 109 after the Battle of Britain (the "L" shaped fuel tank below and behind the pilot seat no doubt constituted a considerable design problem). Eventually most Bf 109F and G models were found to be fitted with a tank made of an inner lining of rubberized fabric and layers of vulcanized rubber, thin raw rubber, thick raw rubber and vulcanized rubber of a total thickness of 15mm boxed inside 5mm of laminated plywood. Chrome-tanned leather was used as a lining according to German sources. The tank weighed 121 pounds compared to 58 pounds for the Bf 109E tank but some weight was saved by partially eliminating the bulkhead in later models. Most German bombers had been equipped with effective fuel tank protection and at least modest armor before the war began.

Unlike the Bf-109E Germany’s twin-engine Bf-110C fighter was equipped with self-sealing fuel tanks before the war began. Based on experience in combat over Norway (Gladiators with four .303 guns; Hurricanes with eight .303 guns) the R.A.F. learned to try to aim at the 110’s engines rather than its fuel tanks. One valuable item Britain sent to the United States was a fuel tank from a crashed Messerschmitt Bf 110. From this the American engineers deduced that the Germans had undertaken extensive pre-war research on fuel tank construction. The Germans sought immunity from 7.92mm fire in their tanks. Although the tank had been constructed in a way that gave adequate protection against rifle caliber fire but not against .50 caliber fire, it embodied innovations that addressed several of the problems the Americans were trying to solve in their tank research.

In the United States research which had been conducted at a low level for years was intensified during 1940. The actual research was conducted primarily by private companies. Foremost among them were the giant tire companies, Firestone, Goodrich, Goodyear, and U.S. Rubber. Their efforts were supplemented by Hewitt Rubber Company and the Aircraft Protective Products Company. Both natural and synthetic rubbers were used. Eventually key chemical and materials manufacturers, Dow, DuPont and Monsanto, provided special plastics and metals. Test facilities were primarily provided by U.S. Army and Navy laboratories at Wright Field and Dahlgren Proving Ground.

Here it might be worth saying a word about testing. Most tests were conducted against tanks secured under static and controlled conditions in a test facility under laboratory conditions. This allowed for scientific analysis of results. However, in most cases firing was done at close range with weapons that replicated but were not necessarily identical with armament used in aircraft. Nor were conditions most likely to be encountered in combat replicated. Test results were valid for the specific conditions of the test. Truly sophisticated testing against a tank embedded in an aircraft structure under dynamic conditions such as in a wind tunnel was conducted relatively rarely. In Britain test results were considered most reliable only if the firing was done against a tank or armor within an aircraft.

Research in the United States differed from that in other countries in that the U.S. decided to pursue tanks that could withstand .50 caliber fire. This produced unexpected results. Many fuel cells were slab shaped aluminum tanks made up of rectangular sections with welded seams. The companies’ first attempts to protect the tanks generally involved applying layers of rubber covering the sides of the tank and cemented at the edges. Some approaches also increased the gauge of aluminum used and rounded the edges of the tanks with overlapping metal at the seams. It was initially thought that a .50 caliber penetration would not be much more difficult to seal than a .30 caliber hole. Penetration holes were expected to be approximately the size of the projectile.

The problem caused by firing a .50 caliber round proved far more difficult than sealing a half inch hole. The Navy trailed behind the Army in tank research but quickly made progress. Testing at Dahlgren showed that at close range the .50 caliber round acted more like a...
pole stuck through the entire tank creating a hydraulic shock or ram effect greater than expected. Instead of a small exit hole, the result was that an entire rubber covered rectangular panel failed. The aluminum welds and cemented rubber came apart. Even when the rear wall of the tank did not fail, the exit hole caused by the projectile tumbling through the fluid contents of the tank sometimes produced an elongated gash two to three inches long. This forced the American engineers in a direction far from merely finding the right material to cover a conventional aluminum tank. Subsequent designs generally involved a rubber bladder incorporating sealant placed within an aluminum shell. Eventually the aluminum shell was replaced with one made of synthetic resin. Tests showed that splinters from the shell sometimes caused more damage than the bullets which penetrated into the rubber tank. Finally the shell was dispensed with leaving a flexible tank in which a minimum of fittings were made of metal.

The American research produced a variety of tank designs. They all had in common a basic structure or bladder that was entirely formed from non-metallic materials. The bladder consisted of layers of materials typically cemented together including three basic elements, an absorbent interior lining and inner and outer layers. The inner layer (typically rubber-coated fabric, synthetic rubber, or flexible plastic) was impervious to gasoline and the one or more interior layers were usually a natural form of rubber (rubber latex, sponge rubber, or partially vulcanized rubber) that swelled when exposed to gasoline. The exterior covering might be of leather, fabric, or composite plastic. The tank was typically installed by suspending it with non-metallic material inside the wing or fuselage of the aircraft.

Metal fittings were kept to a minimum. The arrangement was similar to an early German self-sealing tank found in a crashed Do 17 and many of the designs incorporated features found in the Bf 110 tank provided to the Americans by the British.

The Bf 110 tank examined in the United States had no external shell such as was common with initial American designs and consisted of multiple layers. A relatively hard inner layer impervious to gasoline was a composite constructed of hardened fabric and synthetic material. A substantial layer of gum rubber was covered by a thin layer of natural latex covered in turn by an outer layer of chrome-tanned leather. The vertical tank dimension was relatively thin. The tank was suspended within the wing leaving space between the tank and the wing structure so that if the tank bulged from hydraulic shock effects it would not be damaged by contact with the aircraft structure.

Among the many contributors to the development of effective self-sealing tanks a few received recognition for special achievements. In 1939 Ernst Eger of U.S. Rubber was working on
puncture-sealing “safety” tires for automobiles for which he was subsequently awarded patents. His wartime work on self-sealing fuel tanks was credited with saving the lives of thousands of pilots in a letter of appreciation issued by the Navy’s Bureau of Aeronautics in 1946. James Merrill of Goodyear was awarded a patent for refinements in methods in manufacturing self-sealing materials. In 1942 he received a citation from the War Production Board particularly pointing out his achievement in developing tank materials that could accommodate aromatic gasolines without deteriorating.

The tanks that proved effective were somewhat complicated. Initially, only partial protection from a .50 caliber fire was achieved. They normally had half a dozen or more layers of material. They were heavy with a typical thickness of the tank wall being at least ½-inch and often ¾-inch (19mm) or more. They soon proved to require careful handling and maintenance.

Britain, Germany and the United States all continued their own developments. Britain was given access to U.S. developments and later participated on a committee formed to standardize fuel tanks between the U.S. Army and Navy. By the end of 1940 several versions of self-sealing tanks had been developed and were in use in these countries. None of these countries had achieved perfection. Sealing could not be guaranteed against all forms of damage. Problems continued with operations in low temperatures. Increased fuel temperatures associated with thick-walled protected tanks also had to be dealt with. Pressurizing the tanks for optimum high altitude performance compromised self-sealing qualities in some tanks. Use of fuels with high aromatic content posed problems. Replacement, storage and maintenance of tanks required great care. Layered rubber tanks were generally heavier than aluminum tanks and fuel volume was often reduced when a self-sealing tank replaced an aluminum tank.* Some aircraft, especially those with integral fuel tanks, were not suitable candidates for refitting with self-sealing tanks.

An upside of the .50 caliber requirement established by the Americans came when they fired 20mm explosive rounds into a .50 caliber-proof tank. A 20mm round detonating in the gasoline would often fail to cause a fire due to lack of oxygen. Moreover the pressure from the explosion did not rupture the bladder. This

* Examples include fuel capacity of the P-39 being reduced from 170 to 120 gallons and the wing tank capacity of the B-25 falling from 912 to 694 gallons.
is not to say that a 20mm round exploding on, or close to the outside of, the tank could not produce catastrophic results. While not perfect, self-sealing tanks had been developed to a high degree of efficiency. As 1941 progressed many Allied aircraft in production received these tanks and some older aircraft were retrofitted. Many aircraft in production were still equipped with aluminum tanks or first generation protected tanks made of aluminum with an external wrap.

Testing revealed another unexpected result before aluminum tanks were abandoned and metal fittings to rubber tanks were minimized. Sometimes a copper covered solid round containing no explosive or incendiary material caused a small flash upon coming in contact with the metal of the tank. This combined with the destructive effect of the hydraulic ram phenomenon caused tanks to explode. The results were unpredictable. Many tests would occur without an explosion and then a series of explosions would occur in successive tests. The cause of this was not understood until it was almost accidentally found that the friction of the round penetrating the aluminum heated the round and tank, sometimes to the melting point of aluminum, enough to cause ignition. Later combat would confirm that aluminum tanks could, but not always did, explode under concentrated hits from close-range fire.

The basic notion of protecting a fuel tank with alternating layers of materials impervious to gasoline and soluble in gasoline was not new in 1940 but it took an intensive program involving the resources of many industrial and government laboratories to actually perfect a tank in the United States. The Germans had obtained satisfactory results with a program that probably applied an approximately equal amount of resources earlier and over a longer period. The basic structure of these tanks could be determined merely by examining an example from a crashed aircraft. That told only part of the story, however, since a large part of the research that went into developing these tanks related to the manufacturing technology required to produce suitable materials and build the tanks. There really was no short cut way to produce effective self-sealing tanks without mastering the manufacturing technology.

Above: Female workers at Goodrich prepare a metal tank to receive a self-sealing cover, 1941.

At right: Workers applying the outer covering to a self-sealing tank
Goodrich workers building forms for the manufacture of self-sealing tanks

A female worker at Goodrich stitches an inner ply to a building form. Women made up a considerable proportion of the work force producing self-sealing tanks.

Above: A female worker irons the cloth covering the heavy paper building forms for bullet-sealing tanks.

At right: Some muscle power was needed to remove forms from a tank after it had been sealed by being heated under pressure.
Installing an access door in a self-sealing tank

This man is inside a self-sealing tank working on fittings for a fuel supply line.

At left: Inspecting a completed tank
Above: Placing unvulcanized tanks in a vulcanizer
In addition to self-sealing fuel tanks other safety systems were also being developed. One of these was spray to cover engine and fuel lines in cooling/oxygen-depriving carbon dioxide (or other inert gases) to suppress fires. Similar systems were also employed to purge fuel tanks that were not self-sealing. This was a more efficient variation of the Soviet exhaust gas system developed years earlier. A variety of armor in various thicknesses was introduced to aircraft. Armor materials varied from case-hardened steel or alloys, to homogenous steel, to aluminum deflector plates depending on the purpose of the armor, availability of materials, type of aircraft and location within the aircraft. Acrylics graduated from a component of safety glass to clear vision “Plexiglas”. Plasticized cellulose acetate sandwiched between layers of glass became “armored” glass. In the United States low-pressure oxygen systems were introduced to lower the threat of explosion compared to high-pressure systems.