

# A Brief History of US Military Aviation Oxygen Breathing Systems

By Christopher T. Carey

## **Introduction:**

The need for special oxygen breathing systems for military aeronautical operations today is taken for granted as being one of the most critically important areas of aircrew life support concerns. When one considers that powered flight itself will shortly become 100 years old (2003), the fact that oxygen breathing systems in aircraft have only been in use for about 86 of those years takes on enhanced meaning. Despite the fact that oxygen delivery systems in military aircraft have been in use for so relatively brief a period, this should not obfuscate the fact that awareness of the need for human beings to breath supplemental oxygen as they rise higher in the atmosphere has been in existence and uniformly acknowledged by physiologists for several hundred years.

In the span of the short 86 years during which military aviation oxygen delivery systems have been in use, the sophistry of life support breathing systems in military aircraft has developed dramatically from the first simple use of heavy iron cylinders to store compressed oxygen (breathed through a short length of rubber hose and a 'pipe-stem' device) in 1917, through the latest *molecular sieve* concentration systems that extract oxygen from the ambient air and compress it for use by aircrew of high-performance jet aircraft (as found in the F-22 Raptor and Joint Strike Fighter prototype, the F-35).

The purpose of this brief paper is not to fully enumerate and chronicle the entire, complex history of military aviation oxygen breathing applications (nor is it to cover the several hundred years of pulmonary physiology research that have enabled development of today's systems), but rather to present a broad overview of *generalised* developments as a starting point for further understanding of this subject. It is hoped that this will therefore serve to stimulate and encourage interest by a wide range of 'non-experts' in this important area of military flight physiology, the importance of which is today almost completely overlooked and taken as granted by the typical aviation minded individual or enthusiast.

## **PART I: 1900 to 1945**

### **Early History: World War One**

Prior to the outbreak of war in Europe in 1914, there had been little if any concern with developing aviator oxygen systems. Although some research had been done on providing oxygen flasks for balloon pilots engaged in lighter-than-air altitude attempts (mostly in Europe, as part of a continuing tradition of medical interest in the effects of high altitude on

balloonists), nothing in the way of an American aircraft oxygen system had been devised or even conceived in practical form.

The first flight of an aircraft using an purpose-provided oxygen system in fact seems to have occurred in 1913, when a French aviator (Georges Lagagneux) flew a Nieuport biplane to an altitude of 20,014 feet (this was 10 years after the internal combustion engine powered Wright Flyer took to the air in December of 1903).

American disregard for the possible importance of providing oxygen systems in aircraft disappeared almost overnight in August of 1914, when the new European war was declared. The rapid advances in aeronautical technology spurred onward by the new war resulted in successively faster and more powerful aircraft, able to fly higher and higher into the atmosphere. This, in turn quickly created awareness by the fledgling US Army medical service of the need to provide oxygen for pilots and aircrews.

This awareness came of practical experience with US aviators flying at higher altitudes (necessitated by the need to fly up beyond the range of ground fire) who needed oxygen to remain alert and be able to function reasonably well in their operation of aircraft. Reports of strange symptoms and seriously debilitating conditions (typical of hypoxia and including cyanosis, headache, weakened muscular tone, earache, vertigo, extreme lassitude) reached medical personnel in operational areas. Further strange, occasional, and unexplained losses of aircraft began to accumulate. It wasn't long before the cause of most of these maladies was pinpointed as being attributable to the need for oxygen use for safe flight above 15,000 feet.

Germany was one of the earliest nations involved in the First World War to recognize and address the need by aviators of aircraft and dirigibles for supplemental oxygen. The great Zeppelin dirigibles, by virtue of their ability to fly at higher altitudes, were the first war craft outfitted with aircrew oxygen systems, which were at first of the conventional compressed gas type, contained in iron storage flasks. Soon, however, the heavy storage flasks were replaced by early liquid oxygen generating systems. These systems were devised and produced by the Draeger Company, a company long associated with respiratory and resuscitation equipment for mining use. Other systems were produced by the Ahrend and Heylandt Company. It wasn't long before some higher flying German bombers and fighters were equipped with these small, lightweight liquid oxygen systems. Oxygen could be breathed from these small 'personal' liquid oxygen systems through use of a mouthpiece (frequently called a 'pipe stem') that could be held clenched in the mouth of an aviator. The tube providing the oxygen was attached (on the German systems) to a large rebreathing bag positioned nearer the unit than the 'pipe stem', so that although the oxygen flow rate was continuous, more of the gas could be saved and reused in the process that would have otherwise been wasted.

These German systems were carefully studied in the United States during the war, after specimens were recovered from downed German machines, and systems very similar in design to the original Draeger systems were soon devised and tested in American aircraft. It wasn't long before several things became apparent. These were that the effects of cold at altitude frequently made it extremely difficult (and at best uncomfortable) to hold an oxygen 'pipe stem' in the mouth for a protracted period. This led to the design of a leather mask in which the small diameter rubber delivery hose could be inserted; the mask, it was

felt, would succeed in both holding the tube in place near the mouth and (perhaps equally as important) provide substantially improved protection against the severe cold encountered in open cockpits at altitude.

Predictably, complaints were soon heard about how the use of a mask was 'restrictive' and would obstruct the wearer's ability to move his head about, in search of a pursuing enemy aircraft. Others felt that the use of a mask would critically distract their attention during dogfighting. These objections were ultimately overcome, however, as the benefit of oxygen use became more widely acknowledged by fliers.

Further areas of study concerned regulation of the oxygen delivery, since originally the continuous flow oxygen systems had featured only a reducing valve that could be opened and closed. Some sort of 'automatic' pressure regulator would be a very desirable improvement in the system (if a successful design could be devised) and the need for a gauge to indicate oxygen supply remaining was also evident. During the war, the French came up with a system named after its creator, Dr. Paul Garsaux. This system used an aluminum 'mask' that could be shaped to conform somewhat to the wearer's face and had inflatable face-sealing bladders to help insure a tight seal (it is interesting to note that the latest US Air Force oxygen masks incorporate a face-sealing bladder on the mask's face-seal, some 85 years after Garsaux's experiments with this feature!). The Garsaux system was tested in the USA and considered for adaptation to US biplanes, but was ultimately rejected owing to faults in the design that made it unreliable at certain times.

An improved Garsaux system addressed these deficiencies, but although tested in the USA, none of the improved Garsaux systems were acquired and used in US flying machines.

In Britain, British RFC research soon proved beyond question the many benefits of oxygen to pilots flying combat missions, so the question of whether oxygen systems were necessary or not was thereupon mooted, and effort was dedicated towards devising lighter, more dependable, and more comfortable oxygen breathing systems for aviators. Siebe, Gorman, and Company, English pioneers in the design and production of respiratory equipment for miners and divers, produced the first practical military aviation oxygen breathing system for the RFC, although it was somewhat heavy and had certain disadvantages. It used a rubber mask without inlet or outlet valving, and featured single or doubled flasks of compressed oxygen (500 or 1000 liters capacity). This system could support one or two men, but after a year of flight experience with this system, the RFC abandoned it and returned to their original system of providing each aircrewman with his own individual oxygen supply.

Not long after this, the "Dreyer Oxygen Equipment" system was developed by LC Geo. Dreyer of the RFC Medical Branch. Designed by Dreyer, after a cooperative RFC/French study of all the major military aviation oxygen delivery systems in use, the Dreyer oxygen system was adopted by the RFC and placed into production by the De Lestang Company in Paris (patent holder). The key to success in the Dreyer system was its use of an aneroid-controlled, automatic regulator design. This pressure-compensated delivery system was entirely automatic, being regulated entirely by the system and not by hand (as in the Siebe-Gorman system). Unfortunately, the system was so precise that each unit had to be manufactured entirely by hand, with the result that production output was limited and

not rapid. American tests of the new Dreyer RFC system showed that it had some deficiencies, but that it was very, very rugged; a review of available systems by these same American researchers suggested that the United States should select and install the improved Dreyer system on American military aircraft.

Owing to the slow production of the Dreyer systems in France, in 1917 arrangements were made to manufacture and produce the improved Dreyer oxygen system. Upon consideration of this intent, it was clear that in order to rapidly mass produce the system in the USA, it would have to be completely redesigned. This proved no easy task in 1918, given the status quo of industry at that early time, however after a massive amount of study and preparation, the system was entirely reconfigured. The new American version of the Dreyer apparatus featured a leather and rubber mask in which a microphone was to be fitted, but it proved very unpopular due to various considerations that included the awkward size of the microphone, bulkiness, and placement of the components. Work done by the A.C. Clark Company on the improved Dreyer system resulted in a new reference to it as the 'Clark-Dreyer System' and many months after the studies began, complicated by extraordinarily perplexing developments, the system finally began to be produced and shipped to France for installation in American war planes.

When the Armistice was finally signed, fewer than 3000 sets of the 'Clark-Dreyer System' regulators and masks had been delivered to American AEF squadrons in France. By the time the war had ended for all combatants, oxygen had been permanently accepted as a necessary part of the life support equipment required by pilots to successfully fly and fight at altitude. Ultimately, however, historical research has seemingly demonstrated that few American combat aircraft flown in the war actually had been equipped with oxygen systems by war's end.

As Glenn Sweeting has stated in his superb book, *COMBAT FLYING EQUIPMENT*, the problem of providing adequate oxygen breathing systems for military aviators in the First World War simply was too great for the amount of time available to devise a suitable system: "...it simply challenged the state of the art and came up short."

As a final note on First World War military oxygen breathing systems, it should be remarked that the systems devised in that extraordinarily compressed early "learning curve period" were not completely adequate, being given to failure and prone to faulty operation, which not infrequently resulted in a loss of both machines and men when the systems failed at higher than normal altitude. Had the war continued on into 1919 and beyond, there is little doubt that improvements would have resulted in far better systems reliability that existed at war's end.

### **Post World War One Developments:**

Although the less-than-satisfactory state of the art status in military aviator oxygen systems was well recognized after the Armistice, wartime demobilization was soon in full swing and all areas of military research and development suffered accordingly. Fortunately, a small but vital cadre of aviation medical researchers in the USA and the UK managed to continue the work begun during the war, albeit on a greatly reduced scale and with a

radically lowered priority for funding. Much of this important work continued at Hazlehurst Field in New York (shortly to be renamed Roosevelt Field), a medical research laboratory, which had been part of the wartime US Army Signal Corps' Air Service medical operations. In keeping with the reduction of the Signal Corps Air Service from about 200,000 personnel at peak strength in wartime, demobilization after the Armistice had resulted in a reduction in strength to about 20,000 men; of this almost half would be further released, per a plan established by Congress. Despite this discouraging situation, Dr. Louis Bauer, by now Chief of the Hazlehurst Field medical laboratory, was able to maintain the laboratory's presence as the core of a fledgling Army Air Service flight surgeon program.

A relocation of the lab to Mitchel Field shortly before the beginning of 1920 (a location less than a mile from the original one), nearly coincided with the 1920 Army Reorganisation Act, a Congressional move that offered a considerable further autonomy to the US Army Signal Corps' Air Service. In 1926 a further reorganisation of the military services resulted in the establishment of the US Army Air Corps (to replace the US Army Air Service). At about this same time, the US Army School of Aviation Medicine, formerly headquartered at Mitchel Field, had relocated to Brooks Field in Texas.

Meanwhile, the lack of a suitable system of military aviator oxygen supply for the Army's aircraft provoked continuing research in this area, as new aircraft designs, benefiting from accelerated wartime technological developments, came into use. The old fashioned manually reduced, continuous flow oxygen system that the 'Clark-Dreyer System' had been intended to replace came back into interim use for most immediately post-war flight operations. By the mid-1920, when the 'Type Designation System' standard nomenclature came into US military use, the old Clark-Dreyer System regulator was designated the 'Type A-1 Regulator'. This post war period saw much research (although on a limited scale) into the need for resolving the discrepancies of the old Clark-Dreyer System and a number of systems from both the USA and other nations were tested. A design eventually known as the 'Prouty-Van Sicklen Apparatus' was engineered by T.C. Prouty and manufactured by the Van Sicklen & Company corporation of Illinois. The automatic regulation of oxygen flow in this system was managed through use of a high-pressure/low-pressure system regulated by reducing valves in both chambers, and featuring a low pressure chamber controlled by an aneroid component assembly. An important difference between this system and the earlier Clark-Dreyer System was found in its use of a constant area orifice, driven by varying oxygen pressure (as opposed to using constant pressure and varying the control valve orifice size).

Extensive testing at McCook Field (the Army Engineering Division Laboratory) and Mineola (the Medical Research laboratory) showed that this new automatic control device had great promise as the core of a lightweight, compact, high pressure automatic regulation system. In 1919 a small number of these new devices had been acquired and tested, although not adopted by the Air Service.

In 1921 the US National Bureau of Standards carried out test on a wide range of oxygen breathing systems, in cooperation with the NACA (National Advisory Committee for Aeronautics) and the US Army and Navy Departments. This comprehensive study investigated both gaseous and liquid oxygen delivery systems, and included the older and newer Garsaux systems, as well as German wartime systems, the Siebe-Gorman system, and the Prouty Oxygen Regulator. Problems remained with liquid oxygen systems,

although the US National Bureau of Standards project developed an American liquid oxygen system in conjunction with the study.

In 1922 a modified version of the Prouty Oxygen Regulator was finally developed and adopted by the US Army, installed as 'standard' on US Army aircraft, and eventually designated the Type A-2 Regulator. The improved Prouty regulator was entirely automatic throughout a range from 10,000 feet through 32,000 feet and only required being tuned on or off by the pilot. It was, as were all of the early systems, a 'Continuous Flow' system (in which there is no intermittent or cyclical delivery, as in a Demand System). The Type A-2 (Prouty) Continuous Flow oxygen regulator was designated 'Limited Standard' in 1927 and continued in use through 1930. Although the advantages of the lightweight A-2 regulator were recognized and appreciated, the problem posed by the weight and limited duration of gaseous oxygen storage system required to supply aircrew for prolonged periods of time remained somewhat thorny. Further, whereas today 'Aviator Grade' oxygen is produced 'bone dry' (devoid of water vapor), in the 20s the water vapor in oxygen supplies was mechanically filtered from the circuits through incorporation of a 'purifier (a glass-wool and chemical scrubber tube); this was not optimal and freezing remained somewhat of a problem in all early oxygen circuits for this reason.

In 1923, owing to investigations into the potential of liquid oxygen generating systems, a new 'LOX' system was devised and entered a period of protracted testing and evaluation by the Army. In addition to being lightweight, 'LOX' systems also were free of impurities and had no water vapor to worry about. Still to be overcome remained many smaller difficulties, such as the inoperability of an inverted LOX system and the fact that the inhalable oxygen produced thereby was super-cool and presented certain problems associated with monitoring of the remaining supplies of the gas.

The first flight with one of the new LOX systems installed occurred in 1923, when a DH-4B aircraft was flown at 13,000 feet for about two hours, as part of a test of a new improved LOX apparatus (designed by the US National Bureau of Standards) that would be designated as the Type B-4. Shortly thereafter a further test flight with this system was undertaken to 20,000 feet. Several other automatic LOX system designs of the German design were also tested and designated as the B-1, B-2, and B-3 Types (none of these were adopted or procured for standard US Army use, however).

By 1926, with the establishment of the new US Army Air Corps, an even newer LOX apparatus was devised and designated the Type B-5; this system remained in experimental status, however, and was never standardised. At this time, owing to the complex problems presented by design and development of fully satisfactory LOX systems, the older gaseous oxygen systems remain in use. It is worth pointing out that at this time, very few routine operational flights took place above about 20,000 feet, thereby somewhat lessening the urgency of development of a completely satisfactory LOX system for standard use.

As of September 1927, US Army Air Corps TO 03-10 established the fact that there was only one standard oxygen regulator in US Army use: the Type A-2 (or Prouty) Continuous Flow Oxygen Regulator. This TO stipulated that supplemental oxygen was required for flights above 15,000 feet, but that the individual need for oxygen varied considerably, consequent to the level of exercise undertaken. A revision of that TO a year later (TO 03-

10-1, dated June 1928) stated that the A-2 regulator was determined to be 'not suitable' for flights over 22,000 feet, owing to various operating parameters of the system. The TO went on to specify that a standard 'manually operated' regulator (such as was used in welding) was to be used in flights whose parameters lay outside the cited A-2 operating limits. A version of this type of commercial pressure-reducing regulator known as the 'Rego' was found to meet the requirement and that apparatus was approved as Limited Standard by August of 1927 (receiving the designation Type A-5); this manually operated A-5 'Rego' regulator was not declared obsolete until as late as 1944! Coincidentally, TO 03-10-1 also contained illustrated, diagrammatic instructions for constructing a 'pipe-stem' type mouthpiece from wood, since a standardised oxygen facepiece (mask) was still not in standard use (nor would one be for a considerable period of time).

Prior to 1928, in view of the fact that no 'standard' oxygen facepiece (mask) design existed, instructions had been provided in US Army Air Service circulars of the period that if a mask were made (by individual flying units for use by their aviators), "...*it should not be fabricated so that any metal parts came into contact with the face*". It was further advised that a small tube, preferably made of hard rubber, could be inserted into a facemask made from leather, and retained by a strap. These pipe-stem mouthpieces were frequently made from wood and shaped with a rounded lip or ridge on the innermost end to help retain the tube in either mouth or mask orifice. Shortly after TO 03-10-1 was circulated in 1928, a rubber facepiece (mask) described as "a loose fitting oxygen mask" and designated as the Type A-1 mask was finally adopted. It featured a metal nipple in the mouth area to which a rubber oxygen tube of small diameter could be attached. The Type A-2 mask consisted of another design that combined the helmet and facemask as an integrated unit, but this design was consigned to experimental status and was never adopted. The Type A-3 mask was virtually identical to the earlier 'winter' (Type B-2) cold protection mask made of leather, to which a rubber oxygen tube fitted with a wooden 'pipe-stem' could be attached. This last Type A-3 mask was never taken out of 'service test' status (which it entered in 1929) and was finally declared 'inactive' in January of 1931.

In 1927 the Engineering Test Laboratory of the Army Air Corps moved from McCook Field to Wright Field. Shortly afterwards, an automatic oxygen regulator of a new design was fielded for advanced testing. This improved regulator, which would replace the A-2 'Prouty' regulator, would be standardised in March of 1930 as the Type A-4 Continuous Flow Oxygen Regulator. Several advancements in the automatic regulation of oxygen flow were provided by the design, which used aneroid control to regulate one or two outlet tubes to provide two separate rates of flow. The regulator began self-actuation in the first models at 15,000 feet, but this was later lowered to 10,000 feet. Amount of flow was thereafter increased proportionate to altitude and would automatically decrease in reverse proportion. While this regulator marked certain advances in regulation of continuous flow oxygen, it suffered from similar faults as its predecessors at altitudes above 20,000 feet. By 1936, it had been declared obsolete. Amazingly, the US Army Air Corps once again reverted to use of the old fashioned manually adjusted regulator to control oxygen flow above 20,000 feet!

By 1928, further American advances in the design of LOX supply (vaporiser) systems had been made. A series of improved models were developed and tested, beginning with the B-6 LOX system (standardised in 1929), the B-7 and B-8 systems (similar to the B-6 but

with varying capacities), the B-9 (this was an experimental system that was actually a redesigned B-4 type), the Type B-10 (standardised in 1930, which had a supply sufficient for a two hour flight to 30,000 feet), and eventually, the B-11 system (which was adopted in 1932 and declared obsolete in 1944), the Type B-12 LOX system (an improved system with a 5 liter capacity, that was also standardised in 1932 and became obsolescent in 1944), and finally, a B-13 system, which was similar to the earlier systems, except that it had a 10 liter capacity. Of interest is the fact that the last main LOX supply systems (B-10, B-11, and B-12) were declared 'Limited Standard' in 1936, when the US Army Air Corps returned to the original gaseous oxygen system as its primary and standard system (gaseous oxygen stored under pressure in steel flasks).

By 1930, it is reasonably clear that technical problems specific to the imperfect operation of all extant US constant flow automatic oxygen regulators above 20,000 feet had severely handicapped further advancements in life support equipment development suitable to match the increasing performance of aircraft. Consequent to this awareness, it was suggested to NACA that LOX systems remain the only suitable recourse for flights above 20,000 feet by key personnel in the Experimental Engineering Section (at Wright Field). Compounding the use of gaseous oxygen systems was the fact that it was still virtually impossible to generate commercial quantities of 'bone-dry' aviator oxygen and however small the quantity of water vapor that remained in aviator breathing oxygen of the time, it was too much to preclude recurrent problems with oxygen line freezing and similar difficulties.

In 1930 a US Navy aircraft reached an altitude of 43,166 feet, with Naval Aviator Lt./ Apollo Soucek wearing "*...an oxygen mask that covered his nose and mouth, but still suffering some impairment at maximum altitude*". The 'impairment' is understandable, given that at this altitude some sort of pressure-demand supported augmentative oxygenation is almost mandatory. Of special note is the fact that this flight was carried out in an open cockpit aircraft (practically the last altitude record attempt thereupon undertaken). Later developments in the development of pressurised crew cabins would contribute immeasurably in raising the human functional operational ceiling and eliminating any physiological limits further imposed by the inherent limitations of attempting high-altitude flight in an open-cockpit aircraft equipped with *only* a constant flow oxygen system.

### **The Immediate Pre-World War II Period:**

Fortunately, in 1933, at the Army's Aeromedical Lab at Wright Field (headed by co-founders Major Malcolm Grow and Captain Harry Armstrong--the latter to become generally known as the 'Father of Aerospace Medicine'), awareness of the need for rapidly advanced, systematized, and scientific research in life support technology was taking hold. After assaying the available knowledge database in aviation physiology, Dr. Armstrong suddenly became acutely aware that there was simply not enough basic physiological knowledge of the effects of altitude upon which to carry out development programs for new pressurised crew cabins and advanced oxygen equipment. A recommendation was made to establish a modern outgrowth of the old Hazlehurst Medical Research Facility, equipped with new high-pressure hypobaric chambers, at the Wright Field installation. This was

successful and the Wright Aeromedical Laboratory work coordinated with Technical Engineering Branch studies to achieve the stated objectives.

Among the chief concerns facing Armstrong and his confreres was the problem of devising a suitable oxygen facemask for delivery of oxygen at higher altitudes. Beyond that, new pressure regulators would be required to complement the design of pressure cabins for aircrew in newer aircraft.

In 1931, a newer oxygen facepiece (mask) had been devised designated the Type A-4 mask. It was based heavily upon experience with the original A-1 leather mask (with its pipe-stem tube), and work with the experimental Types A-2 and A-3 masks. This A-4 mask was a combined 'winter' and oxygen delivery mask that comprised a chamois leather lined outer leather shell, fitted to the face through use of an elasticized strap and buckle attachment. The exterior of the mask was wind-resistant, while openings in the facepiece for the eyes allowed standard glass goggles to be used on it. Rubber inlet tubes allowed a small-bore oxygen delivery hose to be attached, while exhalation channels in the leather allowed exhaled air to be routed from the nose area to outlets above the cheek areas. Padded protrusions (filled with Kapok) were situated at the lower margins of the eye holes, so as to shield the goggles from fogging effects of moisture laden exhaled air. The A-4 mask was standardised in 1931 and was carried in limited standard use until 1933. It was not obsolesced until stocks were depleted in 1942. The A-5 mask, a similar full-face combined wind-protection and oxygen delivery mask made from chamois-lined horsehide, was standardised in 1935 and dropped as obsolete in 1943. The last of these leather, combined wind and oxygen mask designs was the Type A-6 mask. The A-6 comprised a multiple-layer mask, with chamois lining, wind-proof exterior surface, and an intermediate layer. The A-6 was not a full-face mask, however, and covered only the lower portion of the face; it therefore came closer to the eventual distinctive shape that subsequent rubber facepiece oxygen masks would feature. It allowed a metal oxygen distributor attached to a small-bore rubber hose to be fitted to the mouth section's exterior, for use with a LOX type delivery system. The mask could be worn without the oxygen distribution tube as a wind protection mask alone, such as might be required in an open-cockpit machine flying at lower altitudes. This last of the old style leather oxygen delivery masks was standardised in 1933, made Limited Standard in 1939, and obsolesced with the Type A-5 mask in 1943. Evidence suggests that it was continued as a 'non-standard and expendable' facemask in USAAC inventories somewhat after that date, however.

Meanwhile, by 1935, the USAAC had acquired considerable experience with both gaseous and LOX type systems in aircraft and felt that it had enough research and practical experience to decide which system was best suited to support present and future aircraft development. A comprehensive report was prepared comparing the advantages and disadvantages of both gaseous and LOX type systems by a committee of the Army Air Corps' Equipment Branch (the chairman of this committee was Dr. Harry Armstrong). Without going into specific details, the report concluded that although there were certain advantages to be derived from LOX systems, the 'state-of-the-art' was still such that these systems posed practical obstacles in terms of storage, field servicing, maintenance, and supply that would make them unsuited to the sort of minimal support conditions applicable to any conceivable wartime scenario in the immediate future. Thus, after due consideration of these findings by USAAF HQ, Air Material Division, and subsequent review by Wright's

Aeromedical Lab and Technical Engineering Branches, the decision was made to gradually phase out all LOX type systems and replace them with standardised gaseous oxygen supply systems from 1936 onwards. Once again, the 'state-of-the-art' had been challenged on a technical front and found lacking at that juncture in time. However, during the following WWII period, renewed interest in the advantages of LOX systems, combined with technical improvements in equipment and methodologies, resulted in a renewed LOX project that finally saw fruition with installation of newer, more satisfactory, and easier to service LOX supply systems in the new jet-powered aircraft of the 50s.

As a consequence, from 1936 until somewhat after the end of WWII, both US Army and Navy aviation relied almost exclusively upon gaseous oxygen delivery systems. With the decision to standardise on gaseous oxygen equipment, renewed importance and priority was placed upon perfecting and improving gaseous oxygen delivery & storage systems; this impetus was spearheaded by the Equipment Branch and Aeromedical Laboratories at Wright Field and the result was development of improved equipment suited to the emerging new requirements.

The Type A-6 Continuous Flow Oxygen Regulator was a manually-adjusted device that emerged from this program, was standardised in 1936 and carried as Limited Standard in 1940, until declared obsolete in 1944. It featured pre-set delivery rates for specific altitudes in increments of 10,000 feet, and was of simple, rugged, and easy to operate design. Initially designed to supply large quantities of oxygen required by the relatively inefficient 'pipe-stem' delivery system, the settings were later changed to suit the lowered demands of the soon-to-follow newer generation oxygen facemasks. The standard US Navy regulator of this period was designated the Type A-7 and used in service-test status for two further years (from 1936 through 1938). Along with these delivery improvements, newer, stronger and lighter compressed oxygen storage cylinders were introduced that allowed a volume equal to a pressure of about 1800 PSIG to be contained within. High pressure extensions carried the gaseous oxygen from central storage cylinders to the various crew station regulators, whereupon a small-bore rubber tube supplied then oxygen under reduced pressure to the aircrew facemask.

With these improvements having been settled upon, and with work on establishing them as standards in new aircraft being manufactured, the more pressing requirement then became development of suitably redesigned and enhanced automatic oxygen regulators for use at higher altitudes, as well as for more efficient modern oxygen delivery masks. Research was immediately undertaken by Dr. Harry Armstrong, Dr. John Helm of the Physiological Research Laboratory, and colleagues in the Wright Equipment Branch to produce a new generation oxygen facemask. Interestingly, at about this time (mid-30s), the success of new fully pressurised aircrew cabins led some investigators to believe that personal oxygen delivery equipment would soon be obviated by the introduction of such refinements (as the pressure-cabin) in the crew compartment of military aircraft. Despite this sentiment maintained by some, research continued at some speed to develop a new aircrew mask. In conjunction with the Army Air Corps agencies charged with this research, commercial and civilian participation in this research was encouraged. Thus medical research organisations such as the Mayo Clinic Foundation in Minnesota participated actively in the investigation of new oxygen breathing equipment. This decision to invite

non-military participation in mask design and development soon would soon prove to be extremely fortunate and foresighted action.

### **The First "Modern" American Aviator Oxygen Mask: The B.L.B.**

Faced with the daunting task of heading up a project charged with developing a suitable military aviator's oxygen breathing mask, Dr. Harry Armstrong and his colleagues at Wright Field soon sought additional ideas and input from the civilian medical sector. The task of designing and producing a functional, yet comfortable and efficient oxygen mask was not by any means a simple one, and similar challenges had been faced with varying degrees of success by others interested in protecting the human respiratory system from chemical gases from about 1900 onwards. Some of the problems associated with use of a facemask include discomfort from having a mask in contact with the skin, inefficient function due to imperfect face sealing, difficulty communicating, and (prior to about 1900, at least) the relative unsuitability of available materials from which to fabricate a satisfactory airtight oronasal mask. Clearly, old fashioned pipe-stem delivery devices were not well suited for use at altitude—especially in open cockpit aircraft—where the effects of cold simply compounded the difficulty of holding a delivery tube mouthpiece in place between the teeth.

This last fact had been discovered by US Army researchers in the late first decade of the 20<sup>th</sup> Century, while attempting to devise a functional gas protection mask to defense against German war gases. They found that even on the ground, the muscles of the mouth have difficulty holding a pipe-stem device or similar mouthpiece tightly between the teeth for even limited amounts of time. The severe effects of cold brought about by flight in the upper atmosphere added considerably to this difficulty. Further, the 'state-of-the-art' of molded rubber was (prior to about 1915) simply not yet sufficient progressed to allow the complex design and molding of a facemask that could be mass produced in a range of sizes suited to fit almost every variation in the broad range of human facial contours. Haldane, along with Messers Draeger and Siebe-Gorman, had all explored this area of work to some extent, facilitated by years of research and experimentation in the development of mining rescue breathing apparatus. Yet none of the existing designs for a reliable, functional, and yet still comfortable face mask were suited for use in upper atmosphere flight.

In the medical field, parallel concerns had somewhat fortuitously developed among medical practitioners, who were interested in devising a method of administering oxygen to critically ill patients by means other than the somewhat dangerous and old style 'oxygen tent'.

At the Mayo Clinic & Foundation in Minnesota, Drs. Walter Boothby, Randolph Lovelace II, and Arthur Bulbulian had been exploring the issue, concerned with the administration of anaesthesia for surgical patients and the administration of oxygen to their respiratory patients. Holding reserve commissions in the US Army, they had also established a special aviation medicine department at the Mayo facility. In 1938, they designed and developed a new type of molded latex rubber mask, which became known as the 'BLB Mask' (named after its inventors). This mask, which covered only the nose, had twin oxygen inlet tubes

that skirted the frontal mouth area to once again join together on the chin, just below the mouth. At that juncture was situated a metal valve that attached to a thin rubber bag and the main small-bore rubber delivery tube. Available in two basic sizes and secured to the wearer's head via straps, the benefits of this mask were immediately obvious for medical applications; when the new mask was subsequently demonstrated to military and civilian aviation medical experts, the applications of this new mask for high altitude flight became apparent to Dr. Armstrong and his team, as well.

A series of tests of the new mask in simulated high altitude situations proved successful, although some problems were encountered with the small valve freezing in cold conditions due to water accumulation. The latex bag attached to the valve had a small plug in the distal end so that any accumulation of water could be drained away, but the bag itself permitted far more efficient use of oxygen flow. Since exhaled human breath contains about 16% oxygen (as opposed to about 21% in ambient air), the exhaled breath could be breathed back into the 'rebreathing bag' where it could effectively be recycled instead of being breathed out into ambient air (and thereby wasted). This permitted lower flow rates of inlet oxygen, among other things—a decided benefit that allowed available oxygen supplies to be extended by a significant margin. Otherwise, the BLB Mask allowed the wearer to talk, drink, and even eat without interrupting the supply of oxygen.

The only obvious drawback of the new mask for flight applications was found in the metal exhalation valve under the chin, which had a tendency to freeze in severe cold conditions (i.e. at altitude). Since most aircraft in the late 30s were starting to be equipped with enclosed cockpit areas, the relatively fragile nature of the thin latex rebreather bag with its susceptibility to turbulent wind conditions could be overlooked. Thus, after evaluation by the Wright team headed by Dr. Armstrong, the BLB Mask was officially adopted by the Army Air Corps and designated Standard Type A-7 in July of 1939. The Type A-7 mask could be used with the manually regulated A-6 or A-8 regulators, a combination which proved highly economical in comparison to earlier 'pip-stem' type delivery systems.

In order to address the problem of the tendency of the A-7's mask's metal valve to freeze, an improved version designated the A-7A was developed in short order. This design did away with the old metal valve and incorporated twin sponge exhalation valves on either side of the hose structure, in place of the metal valve body; the improved A-7A mask was standardized in June of 1943. A further subsequent modification of the A-7A led to the A-7B mask, which appeared quite similar to the A-7A (this mask was standardised in June of 1945).

Meanwhile, problems using the A-7 mask in certain combat situations emerged. Among these were the fact that combat conditions frequently made aircrew forget to breathe through their noses; furthermore, nasal passages were prone to congestion and blockage, whereas the larger oral air passage was rarely occluded. These insights led to the development of the A-8 oronasal mask, which covered both nose and mouth. The A-8 mask was secured by straps to a flier's head or helmet in a manner identical to the A-7. It featured a single large frontal exhalation valve, covered by a sponge disc which could be cleared of ice with a simple squeeze. Unforeseen was the fact that this feature served to partly obscure the forward, downward field of vision, however (important for an aircrew function such as that of the bombardier), so a further refinement was produced that featured bilateral sponge covered exhalation ports on each side of the facepiece. This left

room in front (where the exhalation valve was formerly located) for a small carbon-element microphone to be installed. The improved A-8 modification of the BLB Mask concept was designated the A-8A mask and standardised in February of 1941. A subsequent further modification of the basic oronasal mask was designated the A-8B mask in November of 1941, and it is worth noting that so successful was the A-8B mask design that it continued to be produced and has been used by military forces until well into the 1980s! Accordingly, it is not unusual to today find specimens with mid-1980s production dates stamped upon them!

The A-8B mask was secured to the flying helmet, rather than to the head itself, using straps that hooked to the helmet. The A-9 fabric flying helmet was the first flight helmet to be produced specifically with these hooks to attach the A-8B type mask. Early examples of the A-8B mask also featured leather straps, while the later specimens used elasticated fabric; the much later versions used nylon straps. Surprisingly, the A-8B mask could also be converted into a demand type oxygen mask through use of components in a special adaptation kit that included one-way valves and a quick-attach corrugated, large-bore rubber tubing used in place of the rebreather bag.

The Type A-7 and A-8 family of masks quickly replaced the old pipe-stem delivery system and a new manual regulator designated the Type A-8 was developed for use with these masks. The A-8 regulator was standardised in 1940 and featured a 3000 PSIG capacity, rendering it capable of being used only with the new masks (and not the earlier 'pipe-stem' devices). A modification of the A-8 was designated the A-8A regulator in 1941 and it remained in service as the new standard regulator, until both (A-7 & A-8) regulators were changed to limited standard when the new 'low-pressure' oxygen delivery systems were developed and introduced in about 1941.

### **Low Pressure Oxygen Systems Replace the Old High-pressure Systems, as War in Europe Looms Anew.**

Advances in aeronautical physiology continued apace with improvements in the oxygen equipment technology itself, as might well be understood given the awareness of the need for a more up-to-date knowledge database in USAAC circles. By 1939, many were convinced that a new international conflict was taking shape as Germany continued to build up its military might and Japan continued to challenge the United States for economic hegemony in the Pacific Rim region.

Among the cooperative results of the Wright Aeromedical Lab group's work at Wright Field and the similar studies conducted by the USAAC's School of Aviation Medicine was the publication of USAAC TO 01-1H-1B (dated April 1938). This Technical Order stated that all personnel would use supplemental oxygen at all times in flights above 15,000 feet and that oxygen would be used at all times during any flying done at night (in order to help preserve good vision and motor skills coordination). Further breakthroughs in aeromedical physiological understanding were accomplished, consequent to determination of recommended 'standard' altitude/oxygen levels that postulated (among other things) that flight above 40,000 feet (even with supplemental oxygen) should not be allowed. This was well prior to the development of pressure-demand oxygen breathing systems that would

soon appear in about 1944, and sophisticated pressurised crew cabins that would work with the pressure-demand systems to allow exceptionally high operational ceilings to become commonplace.

Concurrent with these enhancements in flight physiology knowledge, experimentation was also initiated in other areas of work, such as on the development of pressure suits and the introduction of low-pressure Demand Type oxygen breathing systems. German aeromedical research in particular had been most vigorous and by the time war broke out in Europe (September 1939), the German Luftwaffe had already introduced a fully functioning, standard low-pressure Demand Type oxygen breathing system into all of its latest aircraft designs. These systems, built by the Draeger Company in Lubeck and also by the Auer Company, pioneered the new concept of pressure-reduced oxygen delivered only on demand by the aviator wearing a mask. Italy, England, and Germany furthermore had all experimented with early full pressure suit prototype assemblies in attempts to permit flight to higher altitudes. Supercharger technology improvements (and later turbocharger systems) also permitted development of moderately sophisticated experimental pressurised cabins for aircraft, particularly in Germany, where aeromedical research had enjoyed intensive support from Hitler's Luftwaffe.

Thus, as Europe again headed into an all encompassing major conflict, the United States was still attempting to catch up in what was soon to be the vitally important area of aeromedical physiology and life support technology (despite the intensive and remarkable research work undertaken by Armstrong and others in America from about 1935 onwards). Most American combat aircraft were at that time still equipped with the constant flow oxygen breathing system that used compressed oxygen stored in high pressure flasks on board the aircraft and delivered to individual crew stations, where it would be dispersed by the old manually manipulated A-6 type regulators and small-bore latex rubber hoses to the 'new' A-7 and A-8 type rebreather masks (that had only recently started to replace old style 'pipe-stem' oxygen delivery devices). A great number of American aircraft (most particularly trainers) at this time were also of the open-cockpit type, wherein effects of wind and severe cold were still considered formidable threats to aircrew efficiency.

Time and circumstance, however, proved favorable to the United States, in that while all of Europe was immediately plunged into war by the events of September 1939, America remained safely out of the conflict. This provided not just an early alert to the inadequacies of the old style oxygen systems, but a 'buffer' of about two years in which to accelerate the response needed to update and replace these old systems sufficiently to meet the challenge of 'modern' war.

In 1940 and 1941, with the RAF already engaged in meeting Germany's challenge in the air, a team of American aeromedical observers led by Dr. Armstrong were able to visit England to take notes on the rapidly expanding conflict, as it concerned the strenuous physiological demands of altitude and combat. Chief among concerns explored by Armstrong and his colleagues were the unsuitability of high pressure oxygen storage cylinders when exposed to projectile penetrations and servicing difficulties that the old style systems required. Initial experimental tests suggested that the high-pressure system then in use be replaced by a less hazardous low-pressure system, since high pressure oxygen flasks penetrated by incendiary projectiles tended to burn hotly or explode, with extremely damaging results to the aircraft. These findings prompted a change over to the

newer low-pressure system in USAAC aircraft—a move that required a new approach to construction of containment flasks carried on board aircraft. This move, while seemingly beneficial to combat aircraft survival, would later be shown to hold hidden liabilities and pose technical servicing problems in the field. Meanwhile, the US Navy as well as the RAF, continued to use reinforced high pressure oxygen containment flasks—complicating existing compatibility issues between US and English support & maintenance logistics, as the war expanded and progressed. Of interest is the fact that Germany maintained a high-pressure oxygen system throughout the war, although it had earlier gone to the new Demand Type low-pressure oxygen delivery equipment (mask) that required use of an automatic high-to-low pressure conversion regulator.

On US aircraft, the new low pressure oxygen system required use of a new Type A-9 manual continuous flow regulator, which while similar to the A-8 type, allowed use of a new lower-pressure 500 PSIG storage flask; this regulator was standardised in 1940. A slightly improved A-9A manual continuous flow regulator came into standard use in 1941 it was virtually identical to the A-9, but incorporated internal flow and needle adjustment valve settings. An automatic continuous flow Type A-10 regulator was introduced in 'service test' status in 1940, but was never standardised, owing to introduction of the new Demand Type low-pressure automatic regulator in 1941. One other regulator introduced at this time was the Type A-11 continuous flow automatic regulator, that was introduced in 1941 and declared limited standard in 1944. It and its successor (the AN-R-15 automatic continuous flow regulator) were intended for use in cargo or transport type aircraft and supplied a number of users wearing A-7 and A-8 type rebreathing masks.

### **The New Diluter-Demand Type Oxygen System: America Enters the War**

As America's entry into the new European War appeared more likely, second thoughts emerged over the wisdom of the Army's conversion to the new 'low-pressure' oxygen delivery system. This became more evident as statistics gathered during the early phases of the war showed that more aircraft had been lost to ground based FLAK than to actual dogfight 'kills'. However, it was far too late to take any action on this somewhat already mooted point, as America's entry into the war was almost a given (as seen by many in the War Department's inner circles) and a low-pressure oxygen standard had been adopted (flasks filled to about 450 to 500 PSIG only, as compared to 1800 to 3000 PSIG in the earlier high-pressure systems).

Armstrong and his team of observers had noted early on that the rates of oxygen consumption required on missions carried out on the newer extended range aircraft (especially on bomber type aircraft, operating necessarily at higher altitudes due to FLAK threats) were excessively high using older continuous flow oxygen systems. By 1941, the US observers had had ample opportunity to recover functioning examples of the new German Demand Type (the Auer Company first developed this system in 1936) oxygen breathing regulators and masks from downed Luftwaffe aircraft. The apparent advantages the German system offered over the older continuous flow systems were immediately evident and the captured technology was quickly removed to the Wright Aeromedical and Engineering Labs for analysis in June of 1941.

The German system used high pressure compressed oxygen storage flasks, which fed a supply of oxygen (still under high pressure) to a novel 'high-to-low' pressure regulator at the individual crew station. The aircrewman was provided with a molded latex rubber facemask lined with soft chamois leather; this facepiece was fitted with a corrugated rubber, large bore and low-pressure hose that featured a quick connect/disconnect fitting on its distal (regulator) end. The German regulator, after reducing the higher pressure, automatically cycled low-pressure breathing oxygen to the wearer only on demand; this was accomplished through use of valving in the regulator and resulted in a remarkable reduction in overall oxygen use (the system satisfied user consumption requirements perfectly without incurring needless wastage). The heart of the German regulator lay in use of a special demand valve engineered by the Draeger Company, a company long experience in both chemical warfare respiratory protection technology and mining rescue apparatus development.

Immediately after arrival at Wright Field, a collaborative effort between the Wright Equipment Lab, the Aeromedical Laboratory, the Bendix Corporation, and the Air Reduction Company ensued, with the object being to design and develop a functional American counterpart to the German demand system. The result of this intensive cooperative effort rapidly produced the first American Demand Oxygen breathing system prototypes. These early systems featured an automatic regulator of the diluter design, meaning that the oxygen concentration was automatically diluted proportionate to the specific altitude's predetermined human oxygen consumption requirement. As such, this reengineered concept was a largely American innovation, although it did share the German use of a venturi dilution control approach and air-mixture valving. The automatic mixture adjustment was accomplished through use of the aneroid capsule, following previous methods. So quickly was the entire project successfully completed, that designs from both Bendix and Air Reduction were standardised by September of 1941—less than 3 months after the original captured German systems had been received at Wright Field. Both designs were type standardised as the new A-12 Diluter-Demand Regulator and with the introduction of the new regulators, the US Army Air Corps at last had an ideally engineered and designed automatic oxygen delivery system—an unrealised goal of aviation engineers and altitude physiologists since the end of World War One!

In operational function, the new diluter-demand system used a suction actuated valve that opened on the initiation of the inspiratory cycle by the user. The mix-selector was usually left in the 'on' position, which automatically selected the correct oxygen/ambient air ratio required by the user up to about 30,000 feet. Thereafter it supplied 100% oxygen. With the mix-selector in the 'off' position, 100% oxygen was delivered at all times, no matter what the given altitude the user was at. Shortly after introduction, due to some confusion over specific meanings, these two selections were relabeled "Normal Oxygen" and "100% Oxygen". The automatic response of the diluter-demand system also accommodated the variable use needs of the user without further inputs from the wearer; it additionally featured an "Emergency" control that would bypass all of the circuitry and deliver a constant flow of 100% oxygen to the wearer, if selected, irregardless of altitude or respiratory needs.

Production of the new Type A-12 automatic Diluter-Demand Regulator was handed over to several manufacturing contractors so as to speed up introduction and supply of the new

equipment. In July of 1942 the A-12 regulator was reduced to 'Limited Standard' by introduction of the replacement Type AN-R-5. [In February of 1945 an improved Type A-12A Regulator was standardised, resulting in the A-12 and AN-R-5 regulators being relegated to 'Limited Standard' status at that time. In addition to the A-12 type regulators, a portable diluter-demand regulator was also designed for use with small 'walk-around' bottles (A-13), for use between crew stations.]

### **The First Diluter-Demand Oxygen Breathing Mask: the A-9**

As part of the new Diluter Demand oxygen breathing system, an entirely new breathing mask was required for aircrew use, since only a mask configured for response to discrete respiratory cycling would suffice (although as previously noted, the older A-8B type continuous flow mask could be retrofitted with valves and a hose that would allow it to be used as a 'demand mask'). This new mask was quickly developed by the combined Aeromedical and Equipment research teams at Wright Field, in cooperation with commercial engineers. The development of this new mask was considerably aided through research done earlier, by various rubber companies in cooperation with the US Army's research teams at Aberdeen and MIT, on the need to devise a new generation molded rubber facemask to protect soldiers against chemical warfare agents. [It is reasonable to conclude that the German demand-type oxygen mask designs had all been carefully studied, as well, since some of the features of the new American masks would bear a striking similarity to features found on their German counterparts.] The new mask was molded of latex rubber and was designed in such manner that any formation of ice in the critical oxygen channels or orifices could be dislodged by gentle squeezing of the facepiece. Early A-9 Diluter-Demand oxygen masks were molded from grey rubber, had a 12 inch long grey corrugated rubber hose(attached to the lower front chin area), and were equipped with a quick attach & disconnect fitting on the hose's distal end that connected to the crew station regulator. Frequently, a variable length hose extension was used between the regulator and the mask's hose, and there was a small pocket in the nose of the mask in which a Type MC-253 or MC-254 microphone could be placed. Construction of the A-9 mask was such that layers of rubber were glued in place to form channels through which exhaled air could be directed. The single inlet valve had a rubber one way flapper valve ('check valve'), which would close off the inspired airflow upon expiration, thereby directing exhaled air out through the expiratory channels in the mask's facepiece.

The new A-9 Diluter-Demand Mask featured a soft, facially conforming periphery, which was issued in only two sizes: large and small. The mask featured characteristic upwards extending cheek flaps, as well as an external wire former in the nose section, and was attached to the B-9 flying helmet with hooks. A separate so-called "Juliette" head strap suspension could also be used with the mask in the absence of a helmet with the attachment hooks. This new mask was standardised in December of 1941, only two days after the Japanese attack on the Pearl Harbor Naval Base, but was changed to Limited Standard on April 20 of 1942 when the improved A-10 Diluter-Demand Oxygen Mask was standardised. Only a very limited number of the A-9 masks was initially procured before the A-10 improved mask was introduced, hence specimens of this early, original model are today in somewhat short supply. The A-9 mask was declared obsolete in August of 1943.

Problems associated with the A-9 mask were found to include less than satisfactory mask retention characteristics under high-G combat conditions, an expiratory valve that was slightly too small, inadequate face-sealing (particularly around the nose section), and a tendency to draw outside air in during inhalation (both around the edges of the mask and through the exhalation ducts). In terms of comfort, an all important criteria in use of any close-fitting facemask, the A-9 mask was a considerable improvement over previous masks, but it was still far from perfect. These shortcomings soon resulted in introduction of an improved mask designated the A-10.

Concurrent with the introduction of new complexities associated with the Diluter-Demand oxygen breathing system, a new requirement arose for more intensive training and instruction of aircrew in use of the new systems. This need dovetailed with concerns over the growing number of aircrew personal equipment items that required not just careful instruction in their safe use, but more complex logistical support and maintenance. Initially, this training was undertaken and carried out by personnel of the USAAF Altitude Training Program and special unit officers known as "Unit Oxygen Officers". Slightly later, and in order to more adequately rectify this growing need, a new officer position was created in European combat squadrons to be henceforth known as the "Personal Equipment Officer". A non-flying officer, his job would be to coordinate inspection, maintenance, and readiness of aircrew personal equipment items and see it to it that all required personnel training, safety orientations, user instruction, and associated support & maintenance work were properly carried out in his unit. This idea worked so well that US Army Air Force Command Headquarters issued uniform Air Force wide orders establishing a Personal Equipment support specialty. providing specific training for officer and enlisted personnel assigned to the new area of work. As the new area of Personal Equipment support grew during the war, so did the administration & logistics of this area of concern itself, eventually resulting in later dedicated Air Force Specialty Codes (AFSCs) created specifically to carry out this work, after the 1947 National Defense Act reorganisation that allowed for a separate and distinct branch of service known as the "US Air Force". ["Personal Equipment Support" of the WWII and Korean eras would later become known as today's modern USAF "Aircrew Life Support Technology"].

Problems with the older continuous flow oxygen system persisted, due to the fact that the Japanese attack on December 7<sup>th</sup> of 1941 rather precipitously drew America into the new war before a successful transition had been made from the old continuous flow system to the newer diluter-demand system. This posed a special concern for the crews in early bombers, who carried out the brunt of the European bombing on long high-altitude missions. Instances of oxygen hoses becoming disconnected, masks (A-8 type) freezing, and/or regulators being rendered dysfunctional due to ice and other faults were quite common and posed serious risks to the crews, who once the combat action started had little time to worry about making required adjustments to their oxygen systems. Despite promising to address many of these concerns, the newer A-9 mask was also not without its own problems, although the concurrently used A-12 Diluter-Demand Regulator worked quite well in nearly all situations.

As the war rapidly absorbed American forces, priority was given to these European bomber crews and their fighter escort units to replace their older continuous flow oxygen systems with the newer diluter-demand system, though this was a process that was

somewhat handicapped by the rapid and compelling development of combat in the European theatre. By 1943, however, most new American bombers reaching European combat theatres were fitted with the new diluter-demand oxygen system; adequate (but barely) training of aircrews to use the new equipment safely had been included in both flight orientation training and advanced flight training, but the effects of this training was complicated by experiences arising in the field that had not been fully or completely anticipated.

Mask freezing in particular, continued to be a serious problem with the new A-9 mask on the longer, higher altitude flights that the European war necessitated. In answer to the many problems left remaining in the A-9 mask, a cooperative team charged with looking into the possibility of creating an improved mask was formed of the Wright Aeromedical Lab personnel, the Acushnet Rubber Company, and several other distinguished members of the NDRC (National Defense Research Committee). This committee, headed by Dr. C.K. Drinker (a noted American pulmonary specialist), selected a design submitted by Mr. Frank Mauer, which was actually a modification of the existing A-9 mask. The improved mask was initially designated the "L-12 proposal".

Upon review, the new mask was standardised (April 1942) and rushed into production. It was molded from grey rubber and featured the same upward sweeping cheek flaps as the A-9, although it had a slightly larger facial contact area, enlarged exhalation valve, and most particularly an additional strap in the suspension component assembly. This additional strap was integrally molded into the nosepiece of the mask, rising directly upwards over the nose and between the eyes, to attach to a helmet or head-suspension assembly. In this respect it greatly resembled the German Draeger Typ 10-6072 mask and other German masks (Typ 10-69, etc) of the 'three-point' suspension type, using a feature that had been in use on some German masks since 1934. [The mask included a small pocket for installation of a T42 (carbon element) or T-44 (magnetic element), but the practical preference of aircrews seems to have been for use of these early diluter demand masks with a standard T-30 throat microphone.] The new mask was placed into immediate production with wartime priority status and was soon being distributed to combat crews within a few months (the first being handed out in late 1942).

Unfortunately, the A-10 mask, while offering some improvement over the earlier A-9 mask, still suffered from certain characteristic faults. Although reports of its freezing were few, it had a tendency to ride too high up on the face to allow a clear and fully unobstructed forward view by the wearer, and yet still tended to slip down over the face in severe combat-induced high-G maneuvering. A wire nose clip was still used to provide proper fitting in this critical area of face-contact, but the wire was uncomfortable, posed a small visual distraction in the field of vision, and did not provide the desired fit expected. Difficulties were also experienced donning the mask, due to its somewhat more complicated suspension system and the need for fighter crews in particular to be in the air at a moment's notice.

The A-10 mask was not declared obsolete until 1946, but was made limited standard with the introduction of several modified versions (A-10 Revised, A-10 Corrected, and the final A-10A mask). Using feedback from field users, an improved A-10 mask was produced in limited numbers known as the A-10 Revised (also known as the Type A-10R) that was standardised in 'late 1942'. Further, a limited number of the existing A-10 masks were

slightly modified and remained in use; these were known as the A-10 *Converted* mask. The Type A-10 Revised mask eliminated the molded rubber third strap between the eyes of the wearer and featured a slightly reduced face-contact conformation. USAAF TO 03-50B-1, dated February of 1943, states that the Type A-10 Revised mask could be readily identified by the presence of 4 characteristic molded-in rubber ridges on each side of the nose section (where the third strap originally had been located). Supposedly also a molded –in "R" was to be found near the manufacturer's trade-mark in the chin-area. The original wire nose shaping component was still present in the original manner as the A-10, although of slightly different shape, and as with previous examples of the new diluter-demand mask, a T-44 (magnetic) or ANB-M-C1 microphone could be fitted. One important modification was the elimination of the upward sweeping extended flaps on the mask's facepiece and the substitution of a new two point strap suspension assembly that had to be used only with a standard fabric or leather flight helmet (such as the A-10 or A-11 helmet); this was the same strap suspension used by the A-14 mask, soon to be introduced. The A-10 Revised Mask was made in 4 discrete sizes and gave fairly adequate protection to the face, assured satisfactory oxygen delivery, and enhanced face-fit adjustment needs. In terms of appearance, the new A-10 Revised Mask had an appearance that is much closer to later appearing masks. Operational use reports showed that despite all the improvements, the A-10 Revised Mask still demonstrated a few areas of serious concern (such as face-fit, sealing, icing, etc.)

Due to the demands made upon Allied aircrew in the massive bomber formations over Europe, the new diluter-demand oxygen masks were still in relatively short supply (despite priority production orders), therefore use of even the slightly less than perfect masks were still required. Consequently, efforts continued towards the goal of coming up with an even more improved version of the A-10 mask. This eventually resulted in the final A-10A Mask, even though the newer A-14 mask was about to be widely introduced (the Ohio Chemical & Manufacturing A-14 mask production was beset with problems dealing with its molds that considerably delayed initial introduction of the new style mask). The new A-10A mask was adopted as a 'Substitute Standard' on October 15 1943, although used less and less as the war progressed and the new style A-14 mask started to come into wider distribution. The A-10A mask benefited from A-10 user experiences that resulted in improved construction and which gave it a slightly different appearance from the A-10 Revised Mask. Most importantly, the A-10A mask featured a more structurally built-up nose section that molded better to the nose without need of the previous and problematic wire reinforcing component. It featured an integrally molded-in microphone pocket, was made in three sizes, and featured the same two-point strap suspension as had the A-10 Revised and A-14 masks.

Despite these additional improvements, problems with mask freezing continued, although these seemed to come mostly from the European Eight Air Force bomber units, which were much more subject to cold and freezing effects at altitude than wearers of the mask in fully enclosed fighter cockpits. In response to this, the Wright team at the Aeromedical Lab was able to devise rubber baffle flaps that helped prevent blockage of the A-10A oxygen inlet ports, although this did not do entirely away with some frost build-up. It should be noted that all of the A-10 masks were made from soft rubber that was difficult to achieve a suitable face-seal with, given the fact that sizing options were limited and not entirely satisfactory to meet the wide ranging facial contours of American servicemen;

fortunately, this was about to change with introduction of the new A-14 diluter demand mask.

Also of note is the fact that as the special difficulties posed by the need to more adequately fit aircrew faces became widely acknowledged, the decision was made to transfer responsibility for engineering requirements from the Equipment Branch at Wright to the Aeromedical Laboratory's newly established 'Oxygen Branch' in April of 1943, headed by Captain Loren D. Carlson. This change in administrative and logistical support for oxygen equipment design and development was to greatly further the success of later research efforts. As part of the new activity undertaken by the Oxygen Branch of the Aeromedical Lab, one of the first purpose-specific anthropomorphic studies was completed (with the cooperation of Harvard University's Department of Anthropology), based upon a precisely measured study of the facial configuration specifications of over 1800 young airmen. This ground-breaking study produced 7 generalised 'standard' facial configurations that were molded into dummy heads and used as a basis for production of more adequate face-sealing facepiece master molds for production of oxygen masks. This allowed optimal production of facepieces that minimised leakage, which was to be best demonstrated in the performance of the A-14 diluter-demand mask, considered one of the best (if not THE best) American oxygen mask produced during the energetic researches of the World War Two period.

Several other areas of work that the Wright Aeromedical Lab engaged in, concurrent with their central concentration of design and development of adequate diluter-demand oxygen masks, included investigations into the possible use of experimental integrated mask/helmet assemblies. Intended as complete protection for the entire human head and respiratory system, several prototype models were produced (these included the plastic Type A-11 oxygen-helmet-mask assembly, and a later improved version designated the Type A-12). A definitive prototype proposal oxygen-mask-helmet assembly was finally produced, designated the Type C-1, but none of these ideas were ever taken off experimental status before the war ended.

### **The Type A-14 Diluter-Demand Oxygen Mask: Benchmark**

Sharing awareness with Army and commercial design engineers charged with the daunting task of helping develop a chemical warfare protective respirator facepiece molded from latex rubber, the US Army Air Corps's Wright Aeromedical Lab teams realised that given the state-of-the-art, their goal of producing a completely functional and fully satisfactory oxygen facemask was an extremely challenging and difficult one. The challenge, both from a medical and engineering standpoint, had shown itself to be immensely complex from the earliest days of such investigations. Experience with the succeeding generations of rubber facepieces had demonstrated that an air-tight seal between face and mask was essential for proper function. This contrasted considerably with the need for such a facepiece to also be comfortable to wear for extended periods of time, since conventional rubber compounds could not meet all requirements for fit, seal, and comfort equally. [This would be a frustrating and recurrent problem that the US Army would face much later again, in attempting to develop a new generation chemical defense facemasks for soldiers in the 1970s.]

Hence, as work on the A-9 and A-10 masks had continued, a separate developmental investigation into perfecting a more suitable diluter-demand mask was carried out in cooperation with the Army, the Mayo Clinic researchers, and the Ohio Chemical and Manufacturing Company. Based upon designs submitted by Dr. Arthur Bulbulian, Ohio Chemical and Manufacturing quickly devised a new design that would eventually be standardised as the A-14 Diluter-Demand Oxygen Mask. The pre-production prototype model of the A-14 mask was completed by October 1941, but much subsequent work was required to perfect this new mask until it was ready for standardisation on 1 July 1943; the molding processes required by the new facepiece were considerably complex and demanding, requiring an inordinately high level of precision on the part of the mold makers and production teams. Initial assessments of the new mask showed that it had great promise, however. So great did its promise appear that it was actually rushed into production before it had officially become standardised. The A-14 facepiece marked a new level of developmental expertise in both engineering design and manufacturing process, as it permitted an entirely new standard in face-seal to be achieved. Molded from latex rubber in a green color, the mask was of sturdy, though flexible construction (much sturdier and less flexible than the A-9 and A-10 series masks). It was molded with a microphone pocket in front of the nose to hold a standard T-44 or ANB-M-1C mic, had a nose shaping wire embedded into the rubber of the facepiece, and used a two-point rubber strap assembly for attachment to A-10 type helmets; it featured a quick release buckle on the right side of the facepiece to allow easy on/easy off donning capability, had a standard corrugated rubber hose with quick release fitting distally, sealed well around the wearer's face, and best of all, was far more comfortable than any previous mask had been found to be by a wide range of wearers.

In initial operational tests conducted in 1943, the mask had been first issued to fighter pilots in Europe, who found the mask quite suitable in virtually every respect. Only when the mask was issued to bomber crews were there found to be problems with freezing, since fighter pilots in their fully enclosed and protected cockpits did not have extremes of wind and cold to contend with. These problems were addressed to a satisfactory extent by the insertion of a rubber baffle flap, which protected the oxygen inlets from fully obstructing the inlets; this idea came from a member of the RAF's Medical Branch and worked fairly well until an electrically heated mask-warming cover could be devised to fully resolve the problem.

When the new A-14 mask was standardised in 1943, it quickly became the principal standard diluter-demand oxygen breathing mask of the late World War Two period. So satisfactory was the A-14 mask found to be that improved models remained in regular use well into the 1980s.

At the time of its introduction, the A-14 mask was believed to be the very best mask of its type ever produced in the United States and appeared to be the ultimate oxygen breath mask that had been so long sought after by American aeromedical researchers since investigations into use of a facemask began, back in the 1920s. Suffice it to observe that one of the major impediments to the successful development of this level of efficient oxygen delivery in a facepiece was the fact that the materials and fabrication technologies of those early decades were simply not adequate to the challenge presented them. It remained for developments in chemical and polymer formulations technology to catch up

with the visions focused upon earlier, before the high level of effectiveness embodied in the A-14 mask's design could finally be realised. [Despite the excellent performance of the A-14 mask design, it should be reiterated that there is still today no such thing as "the perfect oxygen facemask", since the human face is different in each distinctive individual.]

A slightly modified version of the A-14 mask would be shortly produced in January 1945; almost too late for use in the war, it featured refinements to the internal baffles and was also manufactured in 4 sizes instead of the A-14's basic 3. This slightly improved model would be standardised as the Type A-14A mask 01/45), examples of which would remain in use in the US Army Air Force in the late 40s, even later be used by the US Air Force in the Korean War, and remain in use in actual fact until the final silicone rubber based A-14B mask was introduced in the 1960s.

### **The Pressure-Demand Oxygen System:**

High altitude flight has always been an attractive goal for the aviation minded adventurer. However, in the first part of the new European war (WWII), it rather quickly became apparent not only that flight to higher altitudes was possible (thanks to newly emerging technology), but that due to the increasing deadliness of defensive weaponry, flight to higher (and therefore paradoxically 'safer') altitudes would soon be mandatory. Mindful of this, and well aware of the basic laws of human physiology that dictate the uppermost limits of human respiratory function, an urgent requirement soon developed at the Wright aeromedical Laboratory for a means by which high altitude flight could be safely reached without protection such as was provided by pressurised cabins or pressure suits.

Standard Demand Type oxygen systems were simply not adequate for extended flights above 30,000 feet. Even on full 100% oxygen at 30,000 feet, the law of partial pressures mandates a severe decline in alveolar oxygen saturation levels of aircrew. Further and even more severe declines were encountered at up to about 40,000+ feet, at which point alveolar oxygen partial pressure produced by ambient pressure at that height was barely capable of sustaining life for a short period of time—despite inspiration of 100% oxygen at ambient pressure.

Some body of medical research had already been accumulated, however, with particular application to treatment of pulmonary edema, by the start of the 1930s; especially of note was that research done by Dr. Alvin Barach at Columbia University. In 1940, Dr. Barach was approached by the Wright Aeromedical Lab to see if his research with higher inspiratory pressures ("positive pressure") might not provide a reasonable theoretical basis for the development of a similar pressure-breathing system that would support human life at higher altitudes. Since the partial pressure of oxygen fell away in direct proportion to the ambient pressure in reference, it stood to reason that breathing oxygen under pressure might help artificially boost the partial pressure of oxygen in the lungs above and beyond the normal limits of flight without it. Captain A. Pharo Gagge of the Wright Aeromedical Lab determined to apply Dr. Barach's work towards this end and using himself as a test subject "flew" the facility's hypobaric chamber to a simulated altitude of 50,000 feet on 12 December 1941, using an experimental breathing circuit of his own design. The NRDC paid careful attention to this fascinating proposal and as a result, quickly initiated a

complete research project whose purpose was to investigate the design and development of a practical military pressure breathing system for use at high altitudes. By June 1942 the J.H. Emmerson Company, specialists in medical respiratory equipment, had come up with a specially modified A-12 Demand Regulator that used a spring weighted valve modification. Other effort was directed towards devising a suitable facemask with which to use the experimental pressure-demand regulator. In 1942 development of a pressure-demand face mask was initiated by Captain Francis Randall, again using anthropomorphic facial measurements of aircrew to produce a mask that would satisfactorily contain the pressure required to allow breathing under pressure, while maintaining an airtight face-seal and also remaining relatively comfortable to the wearer. The prototype mask Randall had devised was initially designated the Type XA-13 mask, and was turned over the Mine Safety Appliances Company (MSA), a company with a long history of research work on mining respiratory rescue and breathing systems, for possible production development. Further, by January of 1943 the Bendix Corporation had brought out an improved (experimental) pressure demand oxygen regulator that was later designated the Type A-17 Pressure Demand Oxygen Regulator.

One of the key components of the A-13 pressure demand breathing mask was the critical exhalation valve design, the initial example of which had been designed by Captain Gagge and his colleague, Captain Randall. Proper function of this valve was responsible for allowing the pressure breathing cycle to be carried out properly. The first functioning engineering specimen of the Gagge/Randall valve was produced by the Linde Air Products Company in the short span of a week. According to the story, an unidentified engineer took the Gagge/Randall exhalation valve drawings and built the first working valve, inserting a small counterpressure spring between the main diaphragm and the compensating diaphragm, despite the fact that this small spring had been lacking in the original Gagge/Randall blueprints. This simple and anonymous modification of the original design is credited with ensuring the fact that the new valve passed every single functional test imposed upon it. Consequently, it was quickly put into production.

The actual first flight test of the new pressure-demand oxygen breathing system was made by Dr. (Colonel) Lovelace in a specially modified B-17E, during which an altitude of over 42,000 was reached. A subsequent test was flown in a specially modified two-seat P-38 Lightning to an altitude of nearly 45,000 feet without incident. The prototype pressure-demand system was then operationally flight tested in the 28<sup>th</sup> Photo-Recon Sqdn in October of 1943 and subsequently adopted for continued photo recce work by the Army Air Force in November of that year. Initial orders were quickly placed with MSA for 4,000 sets of equipment consisting of the new MSA produced A-13 mask (fitted with the Linde-modified pressure-compensated exhalation valve) and a new Aro A-14 pressure demand regulator that was still under development.

The first operational combat mission flown using the new pressure-demand oxygen equipment was carried out in February of 1944 by the RAF Spitfire flying 14<sup>th</sup> Photo Recon Sqdn, and in April of 1944 the new system was used in bombing missions over the German capitol. By late 1944, all F-5 and F-13 aircraft were fitted with the new Type A-14A pressure demand oxygen regulators and pilot training was carried out in several US ZI (Zone of the Interior) training bases. Several squadrons of Photo Recon aircraft in the

Pacific Theatre were also equipped with the initial pressure-demand breathing system, as well.

According to source documentation, the original experimental A-13 mask was made from very hard green rubber and was referred to as the "XA-13" mask. It was used with the "XA-16" portable pressure-demand oxygen breathing regulator. However, the original rubber compound was found to be too hard and did not sufficiently conform to facial contours, so the production model manufactured by MSA was produced in a medium-green natural rubber compound that was softer and therefore more capable of providing a firm, air-tight face seal on the user's face. The A-13 type mask was distinctive for featuring two black rubber one-way check valves in the inlet circuit that were covered by transparent plastic protective covers, opening downward and marked with an arrow to show proper directional orientation. The exhalation valve, which has been previously described in some detail, was manufactured by MSA and was located in the bottom frontal part of the inner mask area. Directly in front of the nose a circular cavity was molded in which a standard ANB-M-1C type microphone could be inserted, for communication.

One of the main and visually distinctive features of the new A-13 type pressure demand mask was the mask's reversed peripheral face-seal lip. This was separated into upper and lower orifices by a horizontal 'bar' of soft rubber that crossed directly over the mouth, just under the nose. This bar served to keep the lateral sides of the facepiece from distending sideways under pressure and removal of the bar (as was occasionally done by wearers for comfort, since the bar could be somewhat irritating to some wearers) could dangerously degrade the mask's ability to contain inlet pressure of the oxygen. The reversed peripheral face-seal served to help press the pressurised mask to the face, when properly secured. [This 'reversed peripheral seal' feature would later be revived and successfully used by the US Army and many foreign nations in development of new 1970s/80s generation chemical defense respirators.]. As with previous oxygen masks produced in the USA and in Germany, the A-13 mask featured full lateral face flaps to help protect the wearer against flash effects and extreme cold. As originally designed, the A-13 incorporated a two point suspension system, using doubled snap tabs on the left side to attach to a flight helmet, while the right side strap assembly featured a quick release buckle so that the mask could be quickly attached and detached, as suited to needs. The rubber facepiece had two upper protrusions (frequently described as "lugs") through which a nose strap was fitted over a shaped black or OD colored plastic nosepiece to help retain the mask; on each lower lateral margin of the mask, two other molded-in protrusions were situated (covering fabric internal reinforcements), where small metal strap buckles were inserted to secure attachment straps. To provide for attachment of the mask to an H-2 type 10-minute emergency bailout oxygen bottle, a "T piece" connector was installed between the end of the mask's chin inlet and the proximal end of the corrugated rubber oxygen supply hose. The H-2 bailout bottle was initially kept in a flightsuit leg pocket, but was later supplied with a tie-on fabric container to secure in place on the leg; a three foot length of small-bore rubber tubing connected the bail-out bottle valve to the mask's "T-piece" connector.

Designed to provide higher inspiratory oxygen pressure than ambient pressure, no effort was required to inspire (other than the end of a regular expiration), as the oxygen was forced into the lungs automatically. Some effort was required to exhale, however, and it was this work that over a prolonged period of time made pressure-breathing at altitude

somewhat tiring. Aircrew using the new mask soon also found that communication using the mask ANB-M-1C microphone while pressure breathing was somewhat unclear. Due to the 'reverse breathing' process pressure breathing required (effortless automatic inflation of the lungs, followed by forced effort expiration), training requirements for proper use of the pressure breathing mask were considerably more detailed.

Only a limited number of the original A-13 pressure demand masks were ordered on January 24<sup>th</sup> 1944, due to the urgent requirements of units scheduled to operationally use the new system, and in August of the same year, the original A-13 pressure demand oxygen mask was designated as 'Substitute Standard' on the same date that the improved A-13A mask was standardised. The improvements to the A-13 design that resulted in the new A-13A standard were a result of feedback from aircrew who had used the new mask operationally, as was the usual custom. The improved A-13A mask was very similar to the A-13 mask in overall appearance, but had a few slight changes incorporated into it. The improved A-13A mask could be used either as a pressure-demand mask, or as a regular diluter demand mask by substitution of a straight rubber flappered exhalation valve for the pressure-compensated exhalation valve and removal of the one-way check inlet check valves. Other small changes incorporated included sturdier OD colored cotton fabric straps for the original black cotton straps, an improved quick-release right side mask attachment buckle, and the mask was issued in three basic sizes (small, large, and medium), just as was the A-13 mask.

Somewhat later, a few additional changes were incorporated into the US Air Force A-13A mask, which included addition of a snap to the nose strap (the snap was added to the left side of the strap cross-piece, for quick attachment adjustments), the substitution of OD or sage green colored nylon straps for the original black or OD colored cotton straps, substitution of sturdier (redesigned) upper and lower buckles for mask strap attachment, and perhaps most importantly, the use of the new A-2 (later to be known as the MC-3) bailout quick-released connector at the distal end of the oxygen supply hose in place of the original "T-piece" bailout bottle connector (between mask body and hose). These changes were incorporated into the mask shortly before the improved A-13A mask was redesignated the MS22001 mask (early 50s).

[The US Navy continued to use the improved A-13A mask well into the 60s, although changes in the suspension were incorporated (this involved use of a Hardman Tool Company mask suspension shell and quick attach bayonets in place of the original snap attached suspension) in the mid to late 50s. Other changes in the US Navy version included use of a single snap at the helmet end of a stitched two-point "Y" fabric strap on each side of the mask (no right-side quick release buckle, as on the Air Force version) up until use of the the Hardman kit became standard Navy configuration. The Air Force version of the mask, soon known universally as the MS22001 Mask, remained in use well into the late 50s and early 60s, at which time it became increasingly supplanted by the newer MBU-5/P pressure-demand mask. A variant version of the MS22001 mask was also designated the MBU-3/P, late in the 50s].

One other type of pressure-demand breathing mask was developed during the later part of the war. This was the Type A-15 pressure-demand oxygen breathing mask. In October of 1943, the Ohio Chemical and Manufacturing Company also undertook to develop a version of the original pressure-demand mask proposal. This Ohio built mask became known as

the A-15 mask; it resembled the A-13 mask in many ways, as both had been alternate versions of the original design proposal, and had many of the same features as the A-13. However, instead of a hard plastic nose piece and two rubber lugs protruding through it (as on the A-13), the A-15 mask used a simple rubber nose strap, attached to the facepiece by the same sort of plastic rivet system used on the A-14 mask (which Ohio had developed and produced). Otherwise, its functional features were virtually identical to those of the A-13 and after service tests conducted by the Army Air Force in November 1944, it was not accepted as having any essential additional benefits to offer over the already accepted MSA produced A-13 design. An improved mask, designated the A-15A, entered service tests in May of 1945, just as the European War was ending. It too had inlet check valves and a pressure-compensated exhalation valve that operated similarly to that used in the A-13, and could also be used as a straight demand mask by installation of a simple flapper exhalation valve and removal of the inlet check valves. Further testing by both the Army Air Force and the US Navy revealed that the Ohio built A-15A mask offered little improvement over the existing A-13, and was noted to perhaps have a few deficiencies in certain respects. Thus the A-15A mask was never adopted for standard service use. As a result, it is today considered a very rare mask and examples are far and few between, owing to its never having reached a regular standard, mass-procurement stage of production.

Pressure-demand regulator development continued with the two versions of the A-14B pressure demand regulator, one by the Aro Company and then other by Bendix. Both were found to have certain defects and as a result of the comparisons, only the Aro regulator was recommended as being kept in use. The revised A-14 pressure-demand regulator became fully standardised on 1 November 1944 as a modification of the Aro Type A-12 regulator (or AN-R-5 regulator). It differed from the A-12 only in having a manual dial added to its control face, to regulate delivery of positive pressure up to about 30.2 TORR over ambient pressure.

Other pressure-demand regulators under development included the Type A-15, and the Type A-16 (which was a low pressure regulator for use at extremely high altitudes). The latter was standardised in February of 1944 but subsequently proved to have a number of problems, so that by January of 1945 it was declared obsolete. Eventual standardisation of the Aro Type A-14 regulator made further development of the A-16 redundant. The very last pressure demand regulator developed in the war years was the experimental Type A-17, previously mentioned.

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References:

- 1) *Combat Flying Equipment: US Army Aviators' Personal Equipment, 1917-1945*, C. Glenn Sweeting, Smithsonian Institution Press, Washington DC, 1989, ISBN 0-87474-894-1 (HB)

- 2) AAFM 55-01-1, *Reference Manual for Personal Equipment Officers*, June 1945, HQ Department of the Army Air Forces (Soft cover)
- 3) *Gear-up! Flight Clothing and Equipment of USAAF Airmen in World War II*, Jon A. McGuire, Schiffer Publishing, Atglen, PA, ISBN 0-88740-744-7, (HB), 1995
- 4) *50 Years of Aerospace Medicine: 1918-1968*, Green Payton, School of Aerospace Medicine, AFSC Historical Publications Series No. 67-180, 1968
- 5) *German Aviation Medicine in World War Two: Volumes I & II*, Prepared by Office of the Flight Surgeon General, US Air Force, 1950.
- 6) *50 Years of Research on Man in Flight*, Charles A. Dempsey, Air Force Aerospace Medical Research Laboratory, US Air Force
- 7) AAF TO 30-105-1, *Your Body in Flight*, September 1944, HQ Department of the (Army Air Forces)
- 8) AAF TO 00-25-13, *Your Body in Flight*, July 1943, HQ Department of the Army (Air Forces)
- 9) AFM 160-30, *Physiology of Flight*, July 1953, Department of the US Air Force
- 10) *The History of Aviation Medicine*, Robin Griffiths, MD, Specialist Paper, Auckland, NZ.
- 11) *Flight Surgeon's Handbook*: 2<sup>nd</sup> Edition, 30 April 1943, School of Aviation Medicine, Randolph Field, Texas,
- 12) *Principles and Practice of Aviation Medicine*, 2<sup>nd</sup> Edition, 1943, Harry Armstrong, MD, Waverly Press, Baltimore, MD.