Supporting Life at 80,000 feet: Evolution of the American High Altitude Pressure Suit

by Christopher T. Carey

It was a typical sun-drenched late morning at Edwards Flight Test Center in Mojave, California. The Physiological Support Division (or PSD, as it is commonly known) technician was demonstrating how an SR-71 crew member eats while maintaining a flight profile of 2,400 miles per hour at 80,000 feet, squeezed into the multi-layered high altitude pressure suit that includes a helmet assembly with a sealed visor. In the Sergeant's hand was an aluminum tube in the shape of a toothpaste container. The tube contained something vaguely resembling apple sauce in consistency, that the pilot squeezed--via a connector probe--through a special port in the front part of the David Clark Company pressure helmet. *"At three times the speed of sound,"* the Sergeant explained, *"the outer skin of the canopy of the SR-71 Blackbird reaches temperatures in excess of 550 degrees Fahrenheit. All you have to do, if you want hot apple sauce for lunch at that speed, is hold the tube against the inner canopy glass for a few seconds."* He held up the aluminum tube with its cylindrical snout and pressed out a dollop for us to see. *"Voila....hot apple pudding!"*

The marvel that is the current David Clark-produced S1031C Pilot Protective Assembly (or PPA for short) pressure suit--used by crewmen who fly the fastest and highest flying jet aircraft in the world--is not quite entirely taken for granted by pilots who depend upon it for survival at the fringes of space. After all, anything that takes a little over half an hour to get dressed up in tends to make an impression on the wearer. However, the ease with which the suit accomplishes its task of protecting man from the hostile environment he flies in might seem to belie its complexity and the amazing history of decades of mainly American research and development which preceded it.

Historically speaking, the remote ancestors of today's high altitude full pressure suit are to be found in the full coverage, dry diving outfits of turn-of-the-century commercial salvage divers, with their ported brass helmets and valve fittings. Despite these superficial similarities, while the full dry suit ensemble worn by divers protected the wearer from the hazards of too much pressure (hyperbarotrauma), today's aviation counterpart protects the occupant from the dangerous consequences of too little pressure at extreme altitude (hypo-barotrauma). Interestingly, Dr. J. S. Haldane is credited, in 1920, with the first documented suggestion that a suit much like a diver's ensemble could probably be devised which would serve to protect an aviator at high altitudes.


Wiley Post Suit 1934

Serious study into methods and technology which would protect aviators from the effects of increased altitude did not begin until the early 1930s, although the idea of full coverage (but non-pressurized) protective aviator's clothing has been with us virtually from the onset of heavier-than-air flight. Whereas prior to that time high altitude flight beyond 20,000 feet was practically limited by operational inadequacies of the conventionally carbureted piston-driven aero-engines of the time, the development of the aircraft supercharger in the 1920s dramatically opened up this previously forbidding area of the skies that lay above the Troposphere. Suddenly, aircraft could fly up to 36,000 feet or higher and the chief concern was no longer how to keep the aviator insulated from the effects of severe cold, but how to protect him from the effects of lowered oxygen partial pressure that characterizes supra-tropospheric regions.

In the United States of the early 1930s, an innovative individual named Mark E. Ridge determined that a pressurized suit, if suitably constructed, would allow him to make a record breaking ascent into the Stratosphere safely in an open balloon. His efforts to interest the American military departments in this endeavor failed, however, and so he turned to renown physiologist Dr. John Haldane in London, where Haldane had been working with Sir Robert Davis of Siebe, Gorman & Company on developmental deep sea diving suits. Together, Haldane and Davis constructed a hypobaric protection suit for Ridge from a substantially altered diving suit. For a number of reasons, Ridge was never able to put the suit to an actual test, although it was tested in Haldane's pressure chamber at simulated altitudes of up to 90,000 feet (somewhat later, a suit based upon the Ridge-Haldane-Davis design was later flown to a British altitude record of 50,000 feet by a Royal Air Force Lieutenant in 1936, as Haldane continued his work in altitude physiology inspired, in part, by Ridge's interest in a concept they both shared).

Another American pioneer aviator of the era was famed aviator Wiley Post, who in 1934 commissioned the B.F.Goodrich Company to manufacture an early pressure suit of Post's own design. The suit, which was at first unsuccessful, was modified by B. F. Goodrich engineer Russell Colley to enable it to hold 2.5 PSIG of pressure (0.85 kg/cm2); after further development of the rubberized fabric and aluminum helmeted suit, Post was finally able to wear it successfully on several record breaking flights to altitudes of 50,000 feet in 1934.

The decade of the 30s, coinciding with the rising fascist tensions in an increasingly militant Germany, finally began to see considerable international competition to set altitude records, as aeronautical engineering advances continued. Accordingly, interest in development of a protective pressurized garment which would allow record altitude attempts to be made safely finally began to take shape and Germany, Italy, England, Russia, France, Spain, Canada, the United States, and a host of other nations all instituted studies aimed at producing a safe and reliable pressurized suit. Among developments of the late 30s, Italy produced a semi-rigid suit which permitted access through an aperture in the back, and while it was found to be impracticable for use in flight due to the limits of rudimentary materials technology of the time, it presaged NASA's research studies for an extra-vehicular (EMU) suit for use with the American Space Shuttle in the '80s and '90s. Germany's aviation medicine institute also produced several designs from 1935 through 1945 and a number of other attempts at producing a high altitude protective garment were attempted by others.

As England continued its work with derivatives of the Ridge-Haldane-Davis suit, in the United States the US Army finally recognized, albeit somewhat belatedly, the potential importance of a fully pressurized protective garment for military aviators and started a classified research program in 1939, designated Project MX-117. Soon several US companies had been drawn into pressure suit developmental investigations; these included the B.F.Goodrich Company (Russell Colley's engineering group), Bell Aircraft Company, the Goodyear Rubber Company, the US Rubber Company, and the National Carbon Company. From 1940 through 1943 a number of original designs were produced by all involved parties. Generally speaking, they uniformly featured transparent dome-like plastic helmets and airtight rubberized fabric garments which markedly restricted mobility and range of motion when fully pressurized. A major breakthrough came in the development of engineer Russell Colley's XH-5 model, with segmented, bellows-like joints at the knees, hips and elbows that improved use of the limbs. This striking visual aspect of the XH-5 suits resulted in their being termed *'Tomato worm suits,'* after the distinctive convolutions of the Tomato Hornworm's body which had inspired the idea.

The US Army's program to develop high altitude pressure suits is purported to have been substantially motivated by a requirement to protect James Doolittle's B-25 Mitchell crews during their planned high altitude Tokyo air raid in 1941. With a change in plans which altered the high altitude penetration to a low-level one, the consequent overriding motivation to develop a suitable pressure suit for the Army Air Corps diminished considerably. The major limiting factor which resulted, in 1943, in the cancellation of the US Army's pressure suit program, was the fact that when fully inflated the suits became inflexible and rigid, thereby making it virtually impossible to perform the wide and complex range of motion tasks required to fly a modern combat aircraft.

Later, the US Navy began to investigate the full pressure suit possibilities in cooperation with the B. F. Goodrich Company and Russell S. Colley, whose XH-5 model of 1943 was generally considered to have been the most advanced of the early suit designs. This led to a progressive series of refinements in the basic full pressure suit design which would later (in the early 1950s) result in the first practical US military full pressure suit for operational use in high performance aircraft. Meanwhile, studies had been going on for some time to develop better anti-G garments for fighter pilots using the inflatable bladder principle. Also, Dr. James P. Henry of the University of Southern California was experimenting with a new concept in aircrew protection. His study of the operational requirements of aircrew tasks, the need to protect them from high altitude and the inadequacy of full pressure suit technology developments, led to the first of what have since become known as capstan type partial pressure suits. Dr. Henry's partial pressure suit operated by imposing mechanical pressure on the body directly, compressing the abdomen and limbs in the manner of a G-suit through the use of inflatable bladders in the abdominal area and pneumatic tubes (capstans) running along the limbs. The wearer's head was fully

enclosed in a tightly fitting, rubber lined fabric hood, the oronasal component of which featured a discrete area in front of the face, fitted with a transparent visor and fed by oxygen delivered through a corrugated rubber hose (the facial assembly of this early helmet has the appearance of full-face, rubberized oronasal chemical and biological respirators in use today).

Although the David Clark Company had been approached initially by Dr. Henry to help develop his suit concept, David Clark anti-G protection contracts for the US government made direct cooperation difficult. Rather, materials and a skilled technical assistant were made available by the company to allow Dr. Henry to continue his development in California. As a result of continued testing, many improvements in the design were suggested.

Meanwhile, with rapid post-war aeronautical development producing a new generation of jet aircraft that would fly higher and faster than ever before, it became apparent that renewed research into pressure suits would be needed. Due to the great cost involved in pressure-suit research that post-war defense cutbacks made even more prohibitive, the Army Air Force and the US Navy agreed to split the research investigations on pressure suits into two areas of special concentration. This resulted in an agreement that the Army Air Force would continue to concentrate on partial pressure (mechanical constriction) suits, such as the Henry prototype, while The Navy and B.F. Goodrich's team (led by Russell Colley) would continue to explore the 'full pressure suit' concept.

US Army Air Force approval of Dr. Henry's work ultimately resulted in the David Clark produced T-1 suit, the first standardized mechanical principle (capstan) type suit authorized for use to protect US Air Force aircrew from the combined effects of depressurization and G forces. The T-1 suit incorporated overall partial pressurisation and anti-G protection, but had no chest bladder. With the advent of new high altitude strategic bombing aircraft (such as the B-47 and B-52) a special variant of the T-1, designated the S-2 partial pressure suit, came into production; while it was intended principally for high altitude bomber crews, it was also used to some extent in experimental aircraft test projects. The S-2 suit had no anti-G or chest bladders and was strictly intended to be used as emergency high altitude decompression gear. In 1951 the US Air Force authorized limited production of the S-2 suit for certain projects, but it was the original T-1 production suit which figured most prominently in the first high altitude jet and rocket propelled aircraft experiments of the late 40s and early 50s

The first protective helmet incorporating a removable hard shell for head protection used with the T-1 suit was designated the K-1 helmet assembly. It consisted of a snug, laced nylon hood which was worn with a two-piece, close fitting, two-part white outer shell; a further improvement of the K-1 helmet made use of a substantially larger, one-piece green fiberglass outer shell. An upgraded version of the improved K-1 helmet was designated the MA-2 helmet (it featured a white painted version of the improved K-1 fiberglass shell, had an AIC-10 communication set-up, and used an improved, high-pressure oxygen delivery hose on its faceplate). Virtually indistinguishable from the later K-1 helmet, except for AIC-10 headset, was the MB-5 helmet.

All the early partial pressure suits were extremely tight fitting and therefore were quite uncomfortable in prolonged use; the reduced comfort of the so-called ‘Henry suit’ was an unfortunate aspect of all subsequent developments of the T-1 and S-2 suits. An improved model designated the MC-1 followed. In 1956 a further improved MC-3 partial pressure suit was introduced that featured a pressure bladder that covered the complete thorax of the wearer, in addition to regular capstan tubes on the limbs. An MC-4 series model was shortly thereafter produced that integrated anti-G protection with the MC-3 type thoracic bladder (the MC-2 type suits were experimental full pressure suits, about which more will follow). The newer suits did accomplish their main purpose--to protect the wearer from the effects of emergency decompression at altitude for further extended periods of time, but it became increasingly clear that full pressure suits would provide a much more satisfactory and suitable solution to the problem of increased periods of extreme hypobaric exposure.

Human physiological research soon resulted the use of the very different appearing MA-1 and MA-3 series pressure helmets, which were far more comfortable designs that integrated helmet internal protection and sizing components into a single assembly (featuring a moveable transparent visor) that could be worn with both full pressure and partial pressure type suits. [Ironically, as R&D work with the much later TLSS program of the 80s would show, developments of ensuing decades would come full circle with a return from the ‘long-term’ survival concept that was then taking hold, back to the original ‘get-me-down’ idea which had produced the earliest 'emergency use only' partial pressure suit designs.]

It is a singularly interesting sidelight that in the early 1960s many of these early partial pressure suits, specifically the T-1, S-2, and MC-1 models--along with the improved K-1 helmet--were declassified and sold to the public as excess military equipment. This came about from the introduction of the newer MC-3 and MC-4 series suits, a development that resulted in contracts for all the earlier suits (T-1, S-2, and MC-1) being cancelled, with existing stocks declared 'surplus to need'. Alert, interested individuals who encountered them by chance in military surplus stores, where they lay languishing in dingy cardboard cartons, could purchase them as curiosities for as little as a few dollars. Not long after this, however, the discarded partial pressure suits were again hastily reclassified from surplus status to be given to NATO nations under the US military assistance program (to friendly European nations). Despite this fact, a considerable number of these suits remain in the hands of military aeronautical memorabilia collectors to this day, dating from that brief period of Air Force policy change. In this context, few who saw them could ever forget the curious "Captain Company" advertisements--first appearing in Forrest J. Ackerman's *Famous Monsters of Filmland* magazine--which offered new and unissued K-1 helmets for $15 and the MC-1 partial pressure suits used with them for only $7.98!

By the late 1950s, the US Navy had progressed through a series of developmental models of the full pressure suit that would ultimately take final form in the Mark IV, Model 3, Type 1, a production suit which US Navy aircrew wore on high altitude flights during cold weather operations. While the Mark IV Model 3 suit provided excellent high altitude protection for Navy aircrews, in 1954 the US Air Force elected to develop a full pressure suit that had its initial basis in the B. F. Goodrich / US Navy model H, a developmental precursor of the Navy Mk. IV. This new requirement arose from the new North American X-15 research rocket powered aircraft program, which would require complex cockpit pressurisation and high altitude pressure suits systems to adequately protect pilots flying the planned X-15 test missions, a decision prompted as much by the decision to use an ejection seat in the new hypersonic experimental aircraft, rather than a jettisonable pilot escape pod. The Navy's Model H suit, as it existed, was unsuited to anticipated future Air Force operational use, but the Air Force acquired a small number of full pressure suits from the Navy along with considerable data from Navy pressure-suit researches and pushed forward. In 1955, the Air Force (Wright-Patterson) Aeromedical Laboratory simultaneously instigated a program calling on the aerospace industries to submit proposals for a full pressure suit design, which would ultimately result in a full pressure suit that would meet the new Air Force X-15 program requirements, a call to which the ILC, David Clark Company, and the B.F. Goodrich Company all responded. [The fact that the Navy, not long after and in close cooperation with the B.F. Goodrich Company, evolved the excellent Mark IV, Model 3 from its considerably less sophisticated developmental model forebears is today a moot point; inter-service rivalry between the US Air Force and the US Navy undoubtedly figured to some extent in the Air Force's impatience with the pace of the Navy's painstaking program of full pressure suit development, but it has been pointed out by knowledgeable individuals that the Navy's final Mk.IV full pressure suit design was not fully suited to the X-15 program's unique requirements.] North American, after winning the contract to develop the new X-15 aircraft, pushed for development of a suitable full pressure suit system to protect its designated X-15 flight test pilot, Scott Crossfield. It should be noted that Crossfield's inputs, along with his excellent engineering expertise, and interest in the pressure suit development aspect of the X-15 program played an important and integral part in the ultimate pressure suit design process that ensued.

Consequent to the Air Force invitation in 1955 to a number of companies to submit full pressure suit designs for consideration, several contracts were awarded and two of the leading designs were designated the XMC-2-ILC (International Latex Corporation, or ILC) and the XMC-2-DC (David Clark). While ILC would later figure significantly in subsequent protective suits for use in the American space program's orbital and lunar missions (utilizing the familiar 'tomato-worm' joint approach and selected for funding by NASA), the David Clark Company design (XMC-2-DC) was chosen for continued concept exploration as a possible suit for the X-15 program. In 1955 the David Clark Corporation had succeeded in bringing about a major breakthrough in suit design through the use of an inner nylon mesh (called *linknet*, using an angled bias fabric approach) to control the effects of overinflation and enhance range of motion, thereby eliminating the need for the tomato-worm bellows at the limb joints and substantially reducing overall bulk. The David Clark XMC-2-DC prototype, although still in need of substantial development, soon evolved into the MC-2 suit that would ultimately become a standardized Air Force high altitude, full pressure garment known as the A/P22S-2 model. [Interestingly, the Soviet Union had reportedly encountered markedly similar 'control' problems in the development of their full pressure suits for space use. The Russian VKK-4 and -6Ms partial pressure suits, as used with their aluminum GSh-4 and -6 pressure helmets in such aircraft types as the MiG-21, bear more than superficial similarity to the American capstan-type mechanical partial pressure suits.

Despite this fact, no other quite so similar or congruent design conformities, coincidental or otherwise, appear to exist with regard to US and Soviet full pressure suit developments. The Soviets developed full pressure suits fully equal in performance to those of the West for military aviation and orbital space applications, but this part of their high altitude life support development remained shrouded for a substantial time in obscurity, many details of which did not fully surface until well after the breakup of the Soviet Union in the late 80s.]

Concurrent with USAF decision to develop the A/P22S-2 from the MC-2 suit, but partly as a result of development difficulties encountered in the MC-2 program, the US Navy's standard Mark IV suit was determined to be compatible with US Air Force aircraft cockpits as an interim suit after certain changes had been made to it. This suit was accepted as a limited production Air Force FPS designated the A/P22S-3 model, and was intended for use until the A/P22S-2 model was finally found to be ready for standardization. Interestingly, the A/P22S-2 suit is regarded by most as the direct precursor design inspiration for NASA's Gemini mission suits, while the US Navy Mark IV suit was clearly the precursor inspiration for the first US orbital (Project Mercury) space suits used in the original American space flights.

The Air Force's refined MC-2 suit (A/P22S-2) underwent, thereafter, a number of one-off 'dash' modifications for use in various high performance experimental aircraft testing programs, several variations of which were extensively used in the X-15 program, protecting flight test pilots at speeds in excess of almost Mach 5 and altitudes of 107,960 meters. Cine and still photographs of that era (60s) often show experimental test pilots dressed in the ubiquitous aluminized fabric covered (David Clark produced) MC-2 & A/P22S-2 type full pressure suits as they tested aircraft at the limits of space. The standard Air Force design which derived from the MC-2, the A/P22S-2 suit, further developed into subsequently improved variant models designated A/P22S-4, A/P22S-6 and A/P22S-6A (David Clark designations for the USAF High Altitude Flying Outfit A/P22S-6 and HAFO A/P22S-6A were S1024 and S1024B, respectively). The distinctive aluminized fabric outer layer which visually characterized the experimental aircraft project MC-2 type suits was intended to provide ultraviolet and thermal radiation protection for flight test pilots. This feature was also used on the Project Mercury suits and coincidentally appears to have captured the imagination of Hollywood's movie makers, as seemingly every science fiction film of the 1970s period depicts characters dressed in silvered 'space suits' of this general appearance.

Regardless of the success of the A/P22S-2 suit and its modifications in Air Force use, it remained to the US Navy's cooperative program with the B. F. Goodrich Company and pioneer suit designer Russell Colley to solve some important problems concerning mobility and full pressurization. One of the most important developments was an aneroid suit controller that maintained suit internal pressurization at precisely 3.5 PSIG. The Mark series of US Navy full pressure suits which followed alphanumerically identified developmental models, included the bulky Mark I (1956), a lighter, slightly reconfigured suit known as the Mark II, an even lighter Mark III suit (some versions with a gold metallic outer layer) with improved internal ventilation system, and three models of the final Mark IV suit, which went into production in 1958 as standard high altitude issue for operational US Navy squadrons. The ultimate Navy Mark IV, Model 3, Type 1 suit featured various enhancements in fit and ease of donning, as well as substantially improved pressurization control. It would go on to be selected as the basic foundation for modification into NASA's early earth-orbital suit (the original Mercury prototype suits were specially reworked Mark IV suits (NASA designated them XN-1 through XN-4 models, but they were referred to by engineers as the "quick fix" suits).

In March of 1972, the US Air Force was officially designated as the lead command (Life Support Special Project Office--LSPRO) for the management of development, acquisition and logistics support efforts involving pressure suits for the US Department of Defense, although a US Naval life support systems representative (through Naval Air Development Center in Warminster, Pennsylvania) was given liaison affiliation to ensure Air Force/Navy compatibility. This resulted in the US Navy agreeing to give up use of its own substantially developed (Mk. IV) full pressure suit assemblies and adopting US Air Force developed suits for its operational requirement. Political circumstances undoubtedly figured significantly in many such decisions made in an era marked by increasing US Department of Defense (DoD) efforts to standardize and commonise materièl needs and requirements for the various US Armed Services. This decision was also a response to the question of which service would assume the lead in US aerospace developments, since many of the programs being conducted by the Air Force and Navy were needlessly redundant. [The best example of this political philosophy at work was perhaps the so-called TFX program, which ultimately resulted in production of the excellent General Dynamics F-111, but only after many years of controversial, problem-plagued development, directly related to attempting to meet the diverse needs of two services with a single, basic system, and the ultimate rejection of the US Navy version of the aircraft as unsuited to its carrier mission requirements.]

Today, the standard high altitude full pressure suits used in almost all atmospheric flight operations, as well as those used in the space shuttle launch-entry mode, are manufactured by David Clark Company of Worcester, Massachusetts, long a leader in anti-G and pressure suit research and development. David Clark Company suits are used, as they have been for many years now, in the Lockheed SR-71 and U-2 type (both military and NASA) reconnaissance aircraft and all space shuttle crew members go into orbit and reenter the atmosphere in garments sharing many similarities derived from their S1030 and S1010 series relations.

Having evolved from its remote ancestor, the original David Clark XMC-2-DC suit first produced in 1956, the Pilot's Protective Assembly (PPA) model S901 worn by the first SR-71 crews, was initially produced for the Lockheed A-12 program in the early 60s. This garment evolved through several improved models that resulted in the S1030 suit, which was developed in the 1970s for SR-71 Blackbird operations. A special variant designated the S1010 PPA was developed specifically for use in the U-2R aircraft in the mid 1960s; this and several S1010 dash variants were later replaced by a further advanced model, the S1031 PPA. In the early 1980s efforts to produce a standard single suit capable of being used by both SR-71 and U-2 crews, yielded the S1031C suit, replacing earlier suits on an attrition basis. The late model David Clark model S1034 PPA is an advanced lightweight full pressure suit which replaces the S1031C (common SR-71/U-2 design) suit and offers significant performance improvements, including enhanced pilot comfort, ease of donning and reduced stress-fatigue. First flown on 20 June 1991, the S1034 PPA was to ultimately replace all earlier David Clark S-series suits in use by the US Air Force (which are design engineered for an approximate 10 year use/life-span).

The earlier David Clark S1030C and S1010B suits were precisely fabricated, multi-layered garments, weighing about 35 pounds each and available in 12 standard sizes. When their precursors were first produced in the late 1970s, each individual assembly initially cost the US Government over $30,000. The per-unit purchase cost of the newer S1031C PPA was nearer $100,000 and the expense of completely rebuilding one is almost as much as buying the newer version. The seven layers of specialized protection included long underwear, a comfort liner, a ventilation layer, a double-walled pressure containment layer, a restraint layer and a gold fabric outer layer (the gold-orange color of which is officially referred to as 'old gold'). The helmet featured an internal sizing and fitting system originally pioneered by the US

Navy in its FPS developments of the late 1950s and has a sealing (clear) and non-sealing (tinted) visor; tubular ports for entrainment of special food and fluids in extruded aluminum squeeze tubes are provided in the chin area. Donning of the earliest suits took about 45 minutes with the help of two technicians and the services of the PSD (Physiological Support Division),

although the donning time has now been substantially reduced in the late model S1034 PPA. Many of the features of the suits were advancements of systems pioneered in earlier precursors made by the David Clark Company, subsequent to the introduction of the archetypal XMC-2-DC model (precursor of the USAF A/P22S-2 suit used extensively in the X-15 project, as noted earlier) with vastly improved, new-generational systems developed from original combined US Air Force and US Navy FPS research programs. The latest of the S-series suits, of which the S1031C PPA is a good example, are equipped with a urine collection system (known as a 'piddle pack') that permits excreted urine to be dispersed in special lower leg semi-solidification storage areas; each suit is integrated to an outer combined parachute harness/vest assembly fabricated from the same 'old gold' colored material as the outer layer of the suit (the harness/vest assembly incorporates a life preserver system and automatic seawater-activated parachute riser releases called *SEAWARS* , for Sea Water Activated Release fittings). Maintaining internal pressurization at a constant 3.5 PSIG utilizing considerably advanced generational developments of the original US Navy aneroid type suit controller principle, the David Clark suits have been protecting pilots of the SR-71 and U-2 type aircraft at high altitude for somewhat over four decades.

As noted earlier in the text, the first 4 flights of NASA's STS Orbiter were made with test crews of 2 persons, each wearing the special S1030A (modified Blackbird PPA known as the Ejection Escape Suit, or EES) assembly and seated in specially adapted SR-71 ejection seats. US Space Shuttle crews on operational flights (STS-5 through Mission 51-L) wore no special protective pressure garments. Instead, regulation NASA blue flight coveralls were worn with the NASA LEH helmet (NASA designation LEH was given to the military AOH-1, an integrated oxygen helmet combination termed the Assembly Oxygen Helmet-1). The NASA LEH (Launch Entry Helmet) was a virtually unmodified US Navy HGU-20/P visored flight helmet that was donned via a unique ‘clam-shell’ hinging mechanism that divided the helmet into joinable fore and aft, semi-hemispherical sections. It featured a discrete oronasal area (face seal) with a sealable, sliding face visor. (Note: The original HGU-20/P helmet had been developed by the US Navy from the USAF HGU-15/P helmet projected for use by interceptor aircrews, but had been discontinued in use after the faceplate-visor was found to severely limit peripheral vision in tactical combat situations.) The helmet provided emergency oxygen in the manner of a standard pressure-demand oxygen mask, as well as crash and smoke protection, and had the appearance of a full pressure helmet, although it was not. Subsequent to the US Navy's decision to phase the integrated oxygen helmet out, the design was somewhat later revived in an adopted form by NASA for use on the early operational shuttle missions. This is the type of helmet assembly which was worn by the crew of the ill-fated Challenger space shuttle in 1986 and the crews which preceded them from the 5th STS flight through Mission 51-L.

With the destruction of STS Mission 51-L on 28 January 1986, a 'fast track' program to provide astronaut high altitude protection was instituted by NASA. This resulted in the multi-layer NASA Launch/Entry Suit (designated model S-1032 LES by David Clark Company), which was developed to provide combined anti-G protection, emergency pressurization, anti-exposure protection, high altitude escape, and sea-survival for shuttle orbiter crews; these partial pressure (twin-walled bladder type) suits were used with a specially integrated parachute, emergency oxygen system and survival kit pack, worn on the back in combination with the suit. The LES, based upon proven technology pioneered in the 1960 USAF CSU-4/P bladder type partial pressure suit, was not used once the earth's atmosphere had been left behind, but provided protection during launch and reentry phases to enhance emergency survival in the event of a catastrophic shuttle malfunction in the Earth's atmosphere (for actual use in an orbital space environment, a highly specialized and entirely different system known as the EMU, or Extra-vehicular Mobility Unit suit, is utilized). Each LES garment weighed, with helmet, approximately 24 pounds (excluding parachute/survival pack).

The latest model shuttle crew suit is the *Advanced Crew Escape Suit*, or David Clark model S1035 ACES, which incorporates further refinements and is a true full pressure type garment developed, again, using proven & qualified technology from the most recent USAF Advanced Lightweight Pressure Suit (David Clark model S1034). This is the suit now worn on

Launch/Entry phases of shuttle orbiter operations, replacing the earlier S1032 LES. The S1035 ACES began initial service use on NASA mission STS-64, 9 September 1994.

Back in the air conditioned confines of the Edwards Flight Test Center PSD (which is the Edwards AFFTC unit, Detachment Two, of the 9th Reconnaissance Wing based at Beale AFB) our PSD life support host was elaborating further on the amazing protective capabilities of the David Clark full pressure suit for his guest from Finland...but thoughts of the hot apple-sauce 'food' tubes strangely persisted. The development of the definitive American high altitude protective flight ensemble over the past 50 years had somehow crystallized and then subordinated itself around the unique thought of heating one's lunch at 90,000 feet, while traveling in excess of three times the speed of sound in a fully enveloping, form-fitting personal cocoon. This novel mental picture somehow reminded us also of our own lunch, which was shortly going to consist of much more, it is pleasing to relate, than a squeeze tube full of hot, pulverized apple paste, in the Edwards AFFTC cafeteria!

[Note: Among the classic 'B' films of the 1950s is a Humphrey Bogart movie release entitled *CHAIN LIGHTNING*, in which Bogey plays a hot-shot flight test pilot who flight tests the new 'JA-3' experimental aircraft. The storyline and plot are typical late 40s drama, but central to the plot are two innovations that are of more than passing interest. The first is an aircrew escape pod, an actual functional design for which was not successfully developed until the 60s and 70s, and the second is a high altitude pressure suit. The pressure suit that Bogey uses in the film is fascinating, despite the fact that it is pure Hollywood conjecture. In the story, the aircraft company founder decides that Bogey's experimental JA-3 will make a transpolar flight at 2000 mph and 90,000 feet (remember, this is 1950)! Consequently, he orders a special pressure suit to be fabricated that will allow Bogey to survive at this altitude and Bogey is presented the completed suit, ready to don, just three days later. In the film, Bogart dons the special suit in a matter of 15 minutes or so, while sitting in a chair just outside the aircraft! Based upon what we know today of the immense complexities of pressure suit and space suit design and fabrication (and the entire team of PSD life support specialists required to assure integrity of such a system), this is a most amusing and fanciful development in the plot of this technologically dismissible but hugely entertaining film. The film is available on home video in the event anyone is interested in seeing what Hollywood conceived of as a viable high-performance jet aircraft escape system and high altitude protective ensemble in the earliest days of American post-war jet aviation.]

POSTSCRIPT:

When this article was originally written, the Lockheed AR-71 was still being flown from Beale Air Force Base in California, as part of the USAF's 9th SRW. With the stand-down of the USAF's SR-71 program, the only aircraft left in the high altitude inventory which requires full pressure suit support is the ubiquitous Lockheed U-2 and there have been plans to also retire that redoubtable bird. It is somewhat ironic that the 'Dragon Lady' has outlasted the substantially more advanced 'Blackbird', but new missions are constantly being devised for this grand old lady of the Stratosphere, since it is the last of the US high altitude strategic reconnaissance aircraft. [Recent developments in the Southwest Asian conflicts in Iraq and Afghanistan have recently (2009) resulted in plans to defer the U-2 retirement indefinitely.]

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