ACHTUNG! SCHLEUDER-SITZAPARAT!

A BRIEF HISTORY OF THE DEVELOPMENT

OF WESTERN AIRCRAFT EJECTION SEAT SYSTEMS

by Christopher T. Carey

INTRODUCTION:

The destructive power of a modern military aircraft is an awesome concept to reflect upon. When one considers the weaponry, performance and powerplant parameters of just about any contemporary military fighter aircraft in use today, it quickly becomes apparent that by comparison, the performance envelope of the body of the human being flying the machine is a considerable number of magnitudes lower than that of his aircraft. One only has to take note of the grim aircraft accident investigation findings regarding disposition of aircrew and/or passengers involved in a catastrophic air crash to be all too aware of just how fragile the human body is when subjected to G-force stresses beyond even a modest level.

The science of aviation technology has progressed far, far beyond the state of development which in December of 1903 saw what is generally recognized as the first (fully documented) successful powered, manned flight--the Wright Flyer's brief but historic launch from the sands of Kitty, Hawk, North Carolina. However, even in that earliest phase of man's pursuit of powered flight thoughts relating to human safety in this new and potentially dangerous environment were not unknown. Obscure references exist from that period (1910) regarding attempts to provide aircrew with escape from crippled flying machines (although of necessity, quite primitive).

The introduction of the new technology of air warfare into the hoary traditions of warfare etiquette resulted in no small amount of reactionary resistance to the phenomenon of aerial battle, let alone the startling concept of providing a safe operating environment for pilots of the early wood and fabric craft. Aviation was at that time an inherently hazardous undertaking, just as it still is today, but to a far greater extent due to the newness of the technology and operating environment. To a certain degree, resistance to early aviation safety concerns centered upon the ancient traditions of military honor and protocol. One did not wish to suffer the dishonor of retreat from battle, according to honorable custom, and therefore many felt that attempts to provide a safe exit from a crippled aircraft were somehow demeaning to the assumed bravery of aircrewmen.

Parachutes, the first practical aircrew safety device, were at first subjected to disdain by the higher echelons of English aviation command in World War One, who felt that their introduction would encourage a lack of firm resolve to 'stay the course' in aerial combat. This was apparently not the case in the the Imperial German High Command, for the Germans soon recognized the value of the new device and started equipping their balloon crews with this escape device; according to reports, some German pilots also adopted the parachute shortly before the war ended.

Although the development of parachute technology developed marginally in the years immediately following the First World War, the same cannot be said for the concept of ejecting an aircrewman from a disabled aircraft. Perhaps this was due to the relatively low performance of the aircraft in use by the end of the war. To some degree, it must have been due to the general feeling that the successful resolution of the First World War had put the need for continued defense development on sustained hold. In any event, most defense technology activities experienced a significant slump immediately after the war, and it was not until Germany’s military resurgence of the 30s renewed international anxieties that defense concerns (including aircrew safety) again became reestablished.

In most cases, if a pilot found himself in trouble in the 20s, it was relatively easy to simply disengage the seat harness and jump over the side of the machine so that the parachute could be deployed for a safe descent. However, as the power and performance of aircraft continued to increase, it quickly became apparent that the risks involved in simply jumping over the side of an aircraft were significant. Especially so if the aircraft were in any manner aerodynamically disabled or damaged in a way that created unusual airframe gyrations or G forces for the aircrew who were trying to exit. Furthermore, as the designs of aircraft became more sophisticated, especially as found in aircraft designs with placement of the propeller driven engine in the *rear* of the aircraft (behind the crew compartment), the need for a device to successfully extract the aircrew safely beyond the tail assembly (and/or rear-positioned powerplant) became more fully focused in the minds of a few astute and enterprising individuals.

GERMAN DEVELOPMENTS THROUGH WORLD WAR TWO

As is the case with many innovations in technology, it was the Germans who were among the first to explore this area of aviation safety in a serious and innovative manner. Owing to the development of Germany's covert military capability in the 1930s, much work was being done in aeronautical engineering research for military aviation applications. As Germany explored and researched a new generation of higher performance military aircraft as part of Hitler's overall build-up of war materiel, the individuals concerned with aviation medicine in the new Luftwaffe recognized a coexistent, renewed need for aircrew safety. This was especially true, since much aeronautical flight testing of new designs was being undertaken, with all the implicit hazards pertaining to that area of technological investigation.

Many ideas occurred to German aeronautical engineers in the process of attempting to address this need for safe egress from crippled aircraft. One of the first was the "boom" concept, in which a pivoted fulcrum, attached to the pilot's harness and powered by a compressed spring, pulls the pilot free of the cockpit in an emergency. Another of the early ideas was very simple--a compressed spring situated under the pilot's seat which when released would eject the occupant (assuming that the canopy had been freed and cleared first, not always an easy thing to do using a manual technique and especially in a seriously disabled aircraft).

Interestingly, both these early ideas were also conceived and evaluated by counterparts in England, at the end of the Second World War and without knowledge of the original pre-war German research. In fact, back in 1930 an enterprising RAF Flight Officer, concerned with the increased performance of a new aircraft his squadron was transitioning into, formulated a design for an "escape seat." Consisting of a pilot's seat mounted on two telescoping tubes, each containing a highly compressed spring, the seat would be pushed with its occupant up into the slipstream of the aircraft when the seat's catch was released. While the seat was not actually ejected from the aircraft, the idea was that in this position it would be easier for the pilot to roll out of his seat and free himself of the stricken plane. The idea was submitted to the English Air Ministry, along with blueprints and a working model, but no further development was ever undertaken, and thus English innovations in aircrew escape would languish until immediately after the Second World War, when the captured German research and development would stimulate new interest in Allied aircrew escape technology.

In Germany, developments in aeronautical technology were accelerating with the introduction of the jet engine, while by 1939, the Luftwaffe's Aviation Medicine branch was actively experimenting with ejection systems, using physiological testing devices that included instruments for measuring the forces of gravity and acceleration on the human body. Their tests has determined rough physiological parameters of human ability to withstand G force onset of about +20G for a duration of about 0.1 second. The German preference was at this time for a compressed gas system of ejecting the aircrew seat, although explosive cartridge propelled seats were also under development. The need for adequate aircrew escape from dive-bombing aircraft such as the Ju-87 *Stuka*, with its sustained high positive G loading during pull-out, significantly motivated investigations into use of high-pressure systems to eject aircrew. The German manufacturer Heinkel maintained chief engineering responsibility for development of all aircraft escape systems, throughout the war, and by late 1942 all German experimental aircraft being flight tested were equipped with some form of Heinkel ejection seat.

With aircraft development feverishly continuing in wartime Germany, Heinkel developed ejection seats finally started being installed in production aircraft, as radical new designs came into use. Although the singular Messerschmidt 262, twin-engined production jet fighter-bomber (*Schwalb*) did not feature such a *schleudersitzaparat* (the German term for 'ejection seat', which translates roughly to "seat catapult device"), reports suggest that at least a few versions (*Sturmvoge*l) had what has been described as a catapult-seat (although it is not clear whether the seat was driven by an explosive charge or by a spring mechanism). Other aircraft, such as the Heinkel He-162 *Volksjäger*, were provided with a compressed air propelled ejection seat. Other aircraft to feature similar systems included the Dornier Do-335 *Pfeil*, the Arado Ar-234B *Nachtigal*, the Heinkel He-177, the Heinkel He-219 *Uhu*, the Dornier DFS-228, and the rocket-powered Messerschmidt Me-163 *Komet* (this last system was spring powered). Additionally, earlier research begun in the late 30s by Heinkel had resulted in the first recorded example of a completely ejectable crew compartment being developed. The rocket-powered Heinkel He-176 (the world's first rocket propelled aircraft) featured a nose section which could be jettisoned in the event of an emergency. Development problems involving successful deployment of the main parachute designed to slow descent of the ejected crew compartment resulted in several innovative engineering designs, and subsequent testing demonstrated that in the event of the crew being disabled, the He-176's crew compartment would enable its occupant to survive a landing within the escape pod with only minor injuries.

The Heinkel explosively ejected seat consisted of a seat bucket assembly mounted on 4 rollers which moved in two parallel channels 42 inches long. The charge used in the two tube catapult consisted of 30 grams of powder, firing much like a conventional projectile cartridge, with the two part catapult tube fixed to the upper end of the seat and at the lower end to the aircraft frame. Ejection velocity achieved was 35 fps, with a stroke of 28 inches and an acceleration of about 12 Gs. Although an experimental compressed gas system achieved a ejection velocity of 57 fps and an acceleration of 27 Gs, the system was massively heavy and presented considerable field maintenance problems with over 1700 psig pressures required for successful operation.

On 13 January 1942, the first known emergency use of an ejection seat occurred during a test flight of the Heinkel He-280 jet fighter. The pilot, a man named Schenck, ejected from his iced-up aircraft after jettisoning his canopy, successfully achieving safe egress from the machine. Although Schenck's was the first known use of an ejection seat for emergency egress, the Heinkel compressed air driven seat used by Schenck was purportedly tested in an experimental ejection from a test aircraft by a Heinkel employee named Busch, prior to Schenck's 1942 ejection. (These facts was unknown outside of Germany until after the end of the Second World War, and for a while it was thought that the first successful emergency ejection was made by a Swedish pilot from his crippled SAAB J21-A1 aircraft--with "pusher" type propeller powerplant--on 29 July 1946).

By the end of the Second World War, more than 60 emergency ejections had been made by Luftwaffe personnel, and German Aviation Medicine branch research in aircrew egress technology had progressed substantially into areas of high-performance aircraft escape systems at proportionately high physiological limits of human endurance. Among the important facts that had became clear to German researchers, however, was that compressed gas driven systems were prohibitively heavy, requiring installation of heavy system components to contain the gas under high enough pressure to perform as required; they were furthermore quite difficult to maintain and keep operational under actual battlefield conditions. Ballistic (explosive) systems were lighter, but the requisite technology, while promising, was still in its infancy. These facts were not lost on American or British scientists going over the German research at war's end.

SWEDEN: CO-PIONEER IN EVOLVING EGRESS TECHNOLOGY

While America's interest in emergency aircrew egress languished for the most part until after the end of the war, Germany was not alone in recognizing the need for increased air crew safety during the 1940s. In Sweden, SAAB Aircraft was developing a pusher-type aircraft to be designated the SAAB J21, and with the attendant work came understandable concerns about how to effectively provide J21 aircrew with an effective emergency escape system. 1939 saw initiation of studies in ejection systems, and by 1941 primary design studies had been finished, with actual flight testing of the explosively deployed seat being carried out in 1942. Bryan Philpott, in his excellent book *Eject! Eject!*, remarks that Sweden's egress program developed in the early 1940s, "...when war, so often the mother of invention, did not provide the spur to the Swedes that it did to the combatant nations..." In fact, Sweden was very much spurred on by the immense threat of being drawn into war against its will, and has long maintained a tradition, its political neutrality notwithstanding, of providing itself with innovative and advanced defense technology--a tradition it shares with Switzerland, and for similar reasons. Regardless of their motivations, with its excellent reputation for scientific and industrial excellence, Sweden enthusiastically went ahead with its initial research into aircrew egress systems. By the end of the war, Sweden's technical and scientific database on emergency escape systems for aircraft was well advanced, although ostensibly entirely independent of any research undertaken by Germany in the same war-years period (this has not been verified, as Sweden, although technically neutral, had strong sympathies with Germany and maintained continuing diplomatic relations throughout the war--thus the possibility of exchange of technical or research information may not be entirely ruled out).

The Type 1/Type 21 seat ultimately evolved into their later Type 2 (Type 29) ejection seat. The Type 2 seat was intended for use in the SAAB J29 (known informally as the *Flying Barrel*), a post-war, swept-wing, barrel shaped aircraft of single engine design. Although substantially similar to the earlier Type 1 (or Type 21) seat, anticipating the highly touted modern McDonnell-Douglas ACES II seat concept as used three decades later in the F16 *Viper*, SAAB canted the seat back at a 30 degree angle to both reduce frontal area as well as improve pilot G-tolerance. At the onset of Swedish investigations into ejection seat design, a decision was made, as remarked earlier, to utilise an explosive cartridge type ejection gun. In the seat used on the SAAB J29, this took the form of 60 gm of explosive fired in a three-stage charge. A further preference of the SAAB designers was for a pilot worn back-type parachute configuration (not attached to the seat as on the Martin-Baker system), employing a seat-contained survival kit. Although seat ejection was originally to have been initiated through use of two strap-devices located at shoulder level, the design was changed to employ a face-curtain actuator similar to that used by the Martin-Baker system (English). A back-up, or secondary, seat actuating device was situated between the pilot's knees, where it was conveniently at hand in the event unfavorable G forces made grasping the face blind actuator difficult (it is interesting to note that this innovation is now used almost uniformly by all current ejection seat systems). Further enhancements to the Type 29 seat were spring footrests intended to protect the pilot's lower extremities and reduce flail injuries. On the whole, the philosophical approach of the SAAB seat was to eject the seat and occupant, thereafter immediately separating them. Successful man-seat separation was further provided for by the introduction of an apron device which was actuated by a separate power gun, actuated after the central harness unlocked after ejection.

When man and seat had cleared each other, the idea was then for the pilot to either manually deploy his back-type parachute or rely on the automatic barometric chute deployment device.

EARLY AMERICAN EFFORTS: THE US AIR FORCE and US NAVY DIVERGE

By the end of the war, captured German research came into the possession of the Allies. Although emergency egress concerns were not significant in the United States until later in the war, the US had made a few insubstantial efforts in this direction in the late 30s and 40s. Among them in 1937 was the establishment by a Dr. J.W. Heim of an impact facility in a hanger at Wright Field (later to become Wright-Patterson Air Force Base / Air Development Center) to investigate the forces of abrupt accelerations on human beings. A simple swing-device suspended on cables, the system could achieve parameters of about 16 Gs with a pulse of 0.15 seconds. There are further unsubstantiated reports of a late 1930s Army Air Corps experiment using a spring-driven, pivoted fulcrum arm to snatch the pilot out of a rear-engined aircraft under development to fling him to safety beyond the propeller arc. Beyond these examples, there is little to indicate a strong interest in emergency egress technology by American aviation medicine proponents until the later stages of the war, when German research and developments in this area came to light. With the acquisition of both German databases in egress research and actual examples of the German Heinkel explosive cartridge ejection seat by the US, immediately the war had ended, the US began to vigorously attempt to gain greater knowledge in this overlooked area of aviation technology.

The new American developmental research spurred on by acquisition of German wartime data branched off into two distinctly different approaches towards the same end, one taken by the US Air Force and one by the US Navy. With the political rivalry between these two services to attain ascendant aviation technology acting as a further goad, two schools of thought on military egress systems formed. The US Air Force researchers greatly favored many of the German findings, among which was the belief that the best manner of obtaining a favorable pilot posture that would minimise spinal injuries was having firing actuation controls built into armrests on the seat. The US Navy, on the other hand, tended to credit the British approach toward establishing correct spinal alignment to best absorb the punishing catapult forces; this school of thought advocated the use of a face-blind pull-handle firing actuator, the theory being that the act of reaching up to pull a blind down over the face automatically positioned the pilot for the most favorable spinal alignment. Neither of the two techniques were ultimately found to be completely perfect, but this resulted in initial US Air Force reliance upon arm-rest triggers and early US Navy adoption of the English

Martin-Baker face-blind actuator system. This variance in developmental approach would remain a primary distinction between early US Air Force and US Navy ejection seat designs well into the 70s.

As regards the catapult itself, suffice it to say that, as in nearly every instance in which captured German research and technological innovations had been acquired, the cartridge-actuated Heinkel seat figured prominently in early US investigations into emergency egress systems; clearly, compressed gas systems (although functionally adequate) required far too great a compromise in terms of added airframe weight and loading.   Along with actual examples of the German seats, associated equipment and physiological testing instrumentation (including a vertical seat-firing tower) were obtained and studied at Wright Field at war's end. With the first American jet fighter already in the air (Lockheed P-80 *Shooting Star*), some sort of ejection system was needed that would extract crew from these fast new machines under emergency conditions. Although the term 'bail-out' remained in use after the first ejection systems were installed in American fighters, the ballistically fired ejection seat provided far more positive results than a simple 'bail' over the side of the aircraft!

American concern with rapid development of ejection systems for US aircraft resulted in a formal policy of sharing the extant database on ejection systems technology among many different (US) aircraft manufacturers, once knowledge of the captured German developments in the field had been made available for analysis. The opinion has been offered and formally stated in Bryan Philpott's excellent book on the subject that this initially had the effect of creating more problems than it solved for the US Air Force. Whereas in Sweden, Germany and England, responsibility for ejection seat development had been given over to a single industrial concern, the proliferation of US corporate approaches to the problem ironically acted against the easy solution of common design obstacles. At least 6 or 7 aircraft manufacturers in the US designed and developed their own ejection seat systems, installing them in their own aircraft; thus design uniformity was largely absent, and attendant system and logistical complexities resulted which would later present technical and materiel problems for field maintenance. The obvious advantage obtained would be a proliferation of widely different researches that would provide a broader database upon which to draw in future egress R&D work.

As early as 1946, the US Navy had determined that England's Martin-Baker Company had satisfactorily pioneered the basic functional principles of pilot egress technology well enough that duplicate or redundant studies by Navy researchers would be both expensive and needless. Thus, the US Navy arranged with Martin-Baker to provide a seat somewhat tailored to US Navy requirements as well as technical support from that company to develop it. Photographs of this first M-B provided US Navy seat show it to be quite similar to that company's 'pre-Mk.I' seat. Along with the actual seat, a 105 foot tall test firing tower was also acquired and a converted Martin B-26 *Invader* (US Navy JD-1) was specially fitted for planned aerial test firings.

With at least 4 different companies working on US Navy jet aircraft designs in 1946, it was decided to issue an ejection seat specification and allow the individual Navy contractors to develop their own systems, as long as each stayed within specific general parameters. These parameters were based largely on the Martin-Baker seat and the standard features that characterised the English egress philosophy founded by Martin-Baker (face-curtain actuator, drogue gun, etc.) and mandated use of standard US Navy parachutes, survival kits, life-rafts, and other equipment. It is worth noting here that both the first US Navy and US Air Force seats were designed to use seat-type personal parachutes (this is evident in the use of characteristic rounded seat pans in all early US Navy seats), which followed the German example (Heinkel).

Initial US Air Force research showed that the Heinkel ballistic system was not powerful enough to use on anticipated Air Force jet aircraft, as the catapult velocity was insufficient for safe ejection at the new Lockheed P-80's maximum operating speed. However, a fairly simple redesign of the basic Heinkel seat by Wright Field resulted in a prototype US seat, which was tested by a live volunteer from a specially modified P-61B *Black Widow* on 17 August of 1946. A visual side-by-side comparison of the Heinkel seat and the American seat reveals distinct and clearly identifiable design concept sharing. Progress was made quickly in developing the concept, however, and the straight-winged Republic F-84 *Thunderjet* became the first production American jet fighter to be equipped with an ejection seat. As mentioned earlier, the USAF approach to ejection seat design called for armrest-actuating triggers (following the German example) which were first raised and then squeezed. Although a conventional seat-type chute was at first used in the original American seat (used in the P-80), a back-type parachute was later incorporated; these were not, of course, attached to the seat (similar to the Swedish approach, but contrary to the English design), but were worn by the pilot. Further, all early American seats were not automatic in that man-seat separation had to be achieved manually, and the pilot freed himself from the ejected seat first, then manually deployed his personal back-type chute after physically pushing himself away from the ejected seat. Only later did refinements come to be incorporated into the system, which included leg restraint provisions, correct separation sequencing, fully automatic seat-separations--all or most of these having been addressed or at least recognized as desirable early on by England’s Martin-Baker Company and quite soon thereafter by the US investigators.

Regardless of the rapid pace of American development in design and production of ejection seats for military aircraft, after the war, there was some small amount of resistance to the use of ejection seats on the part of American aircrew, who were somewhat reluctant to fly aircraft equipped with them. More than a few pilots likened the prospect of being seated directly upon a seat's live explosive charge akin to sitting on a powder keg with a short fuse. Purportedly, these anxieties were largely put to rest in 1949 by a series of demonstration ejections carried out by Air Force Captain Mazza from the aft cockpit of a specially modified TF-80C *Shooting Star* (later standardized as the T-33 jet trainer). The first US Navy emergency use of the new seat occurred later in the same year when the pilot of a McDonnell F2H-1 *Banshee* was forced to eject at 597 mph over South Carolina. After these events took place, acceptance of the new device was more readily forthcoming among US air crews. In August of 1949 the pilot of an Air Force F-86 *Sabre* also made a successful emergency escape using the new type seat (North American model T-4E-1 catapult seat), again demonstrating functional performance under adverse conditions.

Again, partly due to the broad approach taken towards development of ejection seat systems among US manufacturers, a number of unusual designs were produced. One in particular, developed for use on the pusher-engined XP-54 *Swoose Goose* featured a downward-accessed pilot seat, which would lower the aircrewman below the belly of the aircraft so as to clear the arc of the prop. While not strictly an ejection seat, the XP-54 design anticipated several future developments of a downward firing type seat on the Boeing B-47 *Stratojet*, and the Lockheed F104A *Starfighter*, as well as the downward firing cockpit system for the experimental XF108 supersonic interceptor (development discontinued after mockups were completed), and the Douglas X-3 *Stiletto* twin jet research aircraft. At the time, the official emphasis on development of a successful US system was on functional adequacy at high altitude and sustained high speed, as this was the envisioned performance area within which safe aircrew egress would be most critical; the obvious need for safe ejection at lower, slower speeds took a markedly subordinate priority in this overall Air Force conceptual view. Given the notable rate of engine failures and marginal reliability that characterised the early turbojet engines, this misplaced priority would subsequently have substantial consequences as well demonstrated in US Air Force aircrew survival statistics of the period.

Principal among the influences governing the US Air Force decision to continue developing downward ejecting systems was the fact that early catapult inertial acceleration velocities were not completely adequate to ensure clearance of jet aircraft vertical stabiliser assemblies. This, in combination with emergent awareness of the future importance of high altitude interception mission requirements, resulted in a failure to adequately address safety concerns related to 'low & slow' modes of flight performance. Unfortunately, the 'downward egress' concept was somewhat less than favorable for a number of reasons, not the least of them being its unsuitability for the critical low-altitude or *zero/zero* mode ejection. This fact was later sadly and graphically demonstrated when emergency use of a downward firing Stanley model C-1 seat on a test flight of the Lockheed F104A Starfighter resulted in the death of Captain Ivan Kincheloe in 1958.

As technical advances continued in seat design, it was quite clear that the problem of providing adequate clearance of fast moving aircraft tail structures presented collateral concerns in terms of increased rates of spinal compression injuries related to catapult inertial acceleration forces. Problems associated with having the catapult thrust force located behind the seat center of gravity included high multidirectional G loading due to aerodynamic tumbling forces, wind-flail injuries, wind-blast effects, man-seat separation problems, and parachute entanglements due to aerodynamic instability of the seats after ejection. The problems attending higher inertial acceleration rates to clear the aircraft were obviously not going to be easily solved with continued use of simple explosive pyrotechnic devices. Despite the statistical evidence of only marginal success in achieving safe ejections in the outermost corners of the flight performance envelope, explosively fired catapults of necessity remained in service until roughly 1958, at which time the first rocket catapults were introduced to American ejection seat design (the Convair F102 *Delta Dart* was the first aircraft fitted with a rocket catapult fired seat, designed by Weber Aircraft Company). [Of interest is the fact that the proof of concept design for the F102--the Convair XF-92A research aircraft--was fitted with an early explosively fired catapult ejection seat originally designed for the Convair XP-81. When the two examples of this combined prop and jet propelled prototype were retired from testing in 1947, this seat was fitted to the XF-92A. Perhaps fortunately, it was never put to 'test' use throughout the duration of that aircraft's flight test program.] Other innovations that were prompted by high rates of spinal injury associated with G-onset forces imposed upon the spine during ejection included the use of variable-density compressible foam in seat cushions, to help reduce or offset accelerative effects on the spinal column. (This same principle is employed today in crash helmet design, for the same end.)

Dr. Robert E. van Patten, former Chief of the Acceleration Effects Branch, Biodynamics and Bioengineering Division of Armstrong Aerospace Medical Research Laboratory (Dayton, Ohio), cites the rapid progress made by the United States in adopting emergency egress systems for its Air Force after the slow initial start at war’s end with reference to the fact that in 1955 the first successful supersonic ejection was made by a pilot from his stricken North American F100A *Super Sabre* after the aircraft went into an uncontrollable dive. The ejection occurred at Mach 1.05 during a test flight, and while he was injured in the process, pilot George Smith survived the accident and fully recovered. This incident took place less than a decade after the first real investigations into egress systems had begun in America at war’s end. Although the technology was improving rapidly, most US ejection systems were engineered to perform best under 'ideal' emergency situations. However, success in achieving a substantial safety record (and vindication of the new rocket powered catapult systems) is demonstrated by the fact that during the Vietnam conflict (1963 through 1975), more than 25% of the US Navy’s RA-5 (A3J) *Vigilante* combat ejections took place at speeds greater than Mach 1.0 (the system in use in that aircraft was the

North American Aviation produced HS-1 rocket powered seat, with zero/zero to 700 knot IAS capability).

Certainly the Korean War provided much valuable information to the US Air Force and American aerospace manufacturers regarding egress design assessment. Philpott in his book cites the fact that in almost 2000 combat ejections experienced by the US Air Forces during the Korean conflict, 60% of the aircrew ejecting experienced no problems during egress. The other 31% experienced difficulties ranging from seat actuation, canopy release, maintenance failures, incorrect ejection posture, slipstream, through-canopy-ejection, premature seat actuation, and so forth. Similar difficulties, as well as ones unique to carrier operations, were reported by US Navy pilots. Although most of the problems were addressed, Philpott suggests that again the vast number of dissimilar ejection seat designs in use in various aircraft compounded quick resolution. A look at the official US Air Force statistics themselves shows a slightly different picture, with an overall (USAF) aircrew survival rate of 77% during the first 5 years of ejection seat operational experience (1949-1953) . In a recorded 4626 emergency ejections incurred under non-combat conditions, from 1949 through 1980, fatal injuries occurred in 838 (or 18%) of those ejections. With the refinements of automatic release restraint systems, automatic man-seat separators, variably-staged parachute deployment systems, and aerodynamic deployment stabilisation devices such as the DART system, survival rates went up in the 1954-1958 period to 81%. Throughout the period of the mid 50s through mid 60s, most USAF aircraft egress systems received continual updating as operational experience provided new engineering understanding of optimal design features. The overall survival rate thereafter remained roughly at a plateau of about 80% until the 1975-1980 period, in which these values fell somewhat for USAF crews (introduction of the ACES II system, with enhanced ejection safety features).

ENGLAND'S MARTIN-BAKER: DEDICATED COMMITMENT

With revelation of the early and substantial foundations in emergency aircraft egress technology developed by Germany and Sweden at the war's end, awareness was acute in England that the logarithmic increase in aeronautical performance parameters required a corresponding capability in aircrew protection and escape. The English Air Ministry sought assistance from Sir James Martin, founder of the Martin-Baker Aircraft Company. Baker was a brilliant self-made engineer and designer who had originally set up his company (in 1929) to manufacture machines and specialised vehicles. Development of his firm into the aircraft business in co-partnership with Capt. Valentine Baker (ex-RAF) had met with marginal success, although it was generally agreed that his abilities were quite substantial and his designs for three successive prototype aircraft had been innovative and progressive. In 1942, the third aircraft (designated the MB3) was lost on a test flight which also killed Capt. Baker. Profoundly affected by the loss of his flight testing partner, it is said that James Martin developed a keen interest in aircraft safety and aircrew survival from this experience.

During the war the company manufactured a variety of products ranging from ammunition feeder belt mechanisms to wing-mounted cable cutters and canopy quick-jettison equipment. During the Battle of Britain Martin's canopy emergency release device quickly gained him recognition, and in 1944 the RAF Air Staff approached the Martin-Baker Company to develop a system whereby the pilot of a disabled aircraft could be safely ejected for a normal parachute recovery. An incident involving a pilot having been killed by colliding with the tail assembly of his aircraft (a jet powered *Meteor* prototype) on bailing out was the instigating cause.

The problem, considered from its medical and physiological standpoints, is a thorny one, and although the German studies of the 30s and 40s had produced a baseline database on the practical limits of human G tolerance, the critical principles of "jolt" and pulse pressure--in other words the rate at which accelerative force is applied--were not fully or completely fathomed. It was not until 1944 in studies carried out in Germany by one Dr. Weisehofer that this last factor became more adequately understood. In England, the concept was grasped more quickly and efforts began to determine how to devise a system which would achieve the required pilot extraction without exceeding the ability of the human body to withstand severe rates of accelerative force. One very early idea was the previously mentioned pivoted fulcrum principle, in which a beam attached to the pilot's harness is actuated by a strongly compressed spring mechanism to pull him free of the cockpit and toss him away from the aircraft's tail assembly. The idea had a certain appeal in that it could conceivably be retrofitted to existing aircraft fuselages with a minimum of difficulty.

For various reasons, this idea was discarded and exploration into an ejectable seat system began in earnest. To develop a keen understanding of the limits of G force sustainable without injury by the human spine (which was the critical structure susceptible to damage) in vertical acceleration, it was necessary to develop a vertically inclined tower, up which a test seat could be shot at various rates of G. Both Sweden and Germany had constructed similar test equipment in their ejection seat programs. In the course of tests, it soon became apparent that it was not the peak gravity (or G) sustained which was the limiting factor in human tolerance, but the rate at which the acceleration occurred. Furthermore, onset of G ought not to exceed 300 G/sec, and proper body alignment during the application of force was critical to avoid spinal injury.

These insights led the English to the development of a two-cartridge gun, which met the physiological limitations while still providing peak G needed, and to various refinements in a seat which would assure proper posture (these included a face-blind actuation device and foot rests, both of which helped the ejectee to assume the desired anatomical alignment for a safe ejection). Still another consideration was revealed, after further study of the physiological function of the human spine while subjected to vertical compression forces. This was what is termed "acceleration overshoot," and is the amount of acceleration experienced by the seated person in excess to that of the seat, due to the construction of the body’s structure. It was found that spongy tissues of the body’s nether side tended to increase acceleration overshoot forces, just as did excessively soft seat cushions.

The earliest prototype Martin-Baker seats were configured with the parachute pack in the seat pan and the water-survival pack & inflatable raft fitted behind the back. This was also the configuration for the earliest production model, the Martin Baker Mk.I seat. This design allowed for increased possibility of acceleration overshoot injuries, as was discovered, and in subsequent Marks, the parachute was moved to a position behind the back, with the water-survival kit stowed in the seat-pan. In subsequent Mark developments, the parachute pack remained in the back stowed position, although with the present generation M-B seats (Mark IX and later), the chute has been moved to the seat’s head-support area.

In September of 1945, development of the prototype Martin-Baker ejection seat had proceeded far enough that a contract was placed for two experimental units which would be flight tested in a high-speed aircraft. The latter turned out to be a *Meteor* F3, and after a number of dummy ejections and corresponding modifications of such components as the drogue chute and its deployment device (a gun was incorporated in place of a spring deployment mechanism), the first English live ejection test was made by test subject Bernard Lynch on 24 July 1946.

It is interesting to note that only 5 days after Bernard Lynch conducted the first successful live test of the Martin-Baker prototype ejection seat in England, a Swedish pilot used the SAAB Type 1 (Type 21) ejection seat in his SAAB J21-A1 pusher-engine aircraft in an actual emergency. Furthermore, over 60 German Luftwaffe aircrew had previously used their Heinkel ejection seats for successful emergency wartime (WWII) ejections. Also at this time, the United States Army Air Force was still weighing the merits of ejection seat systems, investigating German wartime developments, and had not even a prototype of its own designed for possible American military aircraft use.

EGRESS MATURES: EJECTION SYSTEMS DEVELOP FURTHER

In June of 1947 the decision was made in England to fit the new Martin-Baker ejection seat (Mark I) to all British tactical military aircraft. A number of versions of the original Mk.I seat were produced for a variety of jet fighters and bombers. Various small changes in the Mark I application for each aircraft type reflected the unique requirements or constraints of that particular plane. The *Meteor* fighter was initially fitted with the M-B Mk.I, and later with the Mk.IE seat. The *Attacker* was fitted with the Mk.IA (it was later upgraded to the M-B Mk.IIA model). The *Wyvern* was fitted with the Mk.IB model (later upgraded to Mk.IIB). The *Canberra* bomber received the M-B Mk.IC seat, and the *Seahawk* aircraft was fitted with the M-B Mk.ID seat (later upgraded to M-B Mk.IID seat). The M-B Mk.IF seat went to the new *Venom* fighter (later upgraded to the M-B Mk.IIF seat).

Prior to full-scale production of the Martin-Baker Mk.I series, the Saunders-Roe Aviation Company placed an order for an ejection seat for use on its Saro A-1 jet flying boat/fighter. This seat lacked some of the more sophisticated features and detailing of the standard Mk.I production model, and was officially designated the Pre-Mark.I Seat. Altogether the Mk.I production seat weighed some 172 pounds (143 pounds of which was ejectable). A list of its innovations includes: 1) a two cartridge ejection gun; 2) gas-pressure release mechanism unlocking the ejection piston from the firing cylinder immediately upon firing of the first cartridge; 3) an adjustable seat pan; 4) spring-loaded footrests to facilitate foot placement for ejection; 5) a face-curtain seat actuation system, which assured proper ejection posture and which protected the pilot's face from blast injury; 6) an explosive drogue gun method of deploying the seat's stabilising drogue chute; 7) retractable seat-pan raising handle; 8) the Martin-Baker back-type water survival/dingy pack, and seat-cushion type personal parachute; 9) integral thigh restraining seat-pan extrusions. By 1950, the Mark I series seat was standard on all first line RAF and RN fighters.

It ought to be noted that there was considerable difference in the physical appearance of the various Mk.I models, and that not all of the dash variations featured a seat type chute. For example, the M-B Mk.IA variant (for *Attacker* aircraft) used a Mk.3A back-type parachute rather than a seat chute, and used a seat sea survival kit/inflatable raft--very much as later seats would. The Mk.IB, ID, IE, and IF seats all featured Type 3A M-B back-style parachute configurations. Only the Pre-Mk.I, Mk.I, and Mk.IC featured seat-mounted chute assemblies. In some cases, the seat style chute was used due to the constraints of the aircraft's cockpit, despite established awareness that acceleration overshoot problems were more of a concern with the seat-style chute design. All subsequent Mk.II series seats featured the back-style chute design.

As experienced in the US, there were initially some reservations about use of the new ejection systems on the part of both aircrew and aircraft manufacturers, who felt that the structural modifications required to fit the seats were costly and technically complex. Again, time and effort was needed to address the reluctance of aircrew to feel comfortable with the new safety devices, but it was not long before several actual in-flight emergency ejections proved the value of the Mk.I type system and these examples of its safe operational value put further hesitance to rest.

Within the first few years the results of about 70 successful ejections (50 of them successful) provided valuable information on much needed modifications to the original Martin-Baker design. The Mk.I system was, after all, a manual seat which did nothing more than successfully get the aircrewman out of his disabled aircraft safely. It was clear that further progress was needed in development, specifically in automating the man-seat separation process and in deploying the personal parachute. In instances where disorientation, confusion and/or disablement were factors in emergency ejections (as they frequently are, especially in aerial combat situations), automated systems would make the difference between saving a pilot or not.

The Mk.II seat addressed these problems. Among the modifications featured on the Mk.II series seats were 1) modification to the drogue shackle, and addition of a Time Release Unit (TRU) for deploying the drogue; 2) a mechanism for releasing the seat harness; 3) addition of an "apron" which would link the drogue chute to the pilot's personal parachute and withdraw it after man-seat separation occurred; 4) a barostatic unit, which was fitted to the TRU so as to prevent deployment above 10,000 feet (oxygen deficit and hypothermia hazards); and 5) further modification of the drogue gun. By 1953 a retroactive modification program was carried out on all RAF and RN aircraft fitted with the original Mk.I series seats to bring them up to Mk.II standards. The effectiveness of the new design resulted in a reduction of ejection fatalities from the earlier, higher figure applicable to the Mk.I seats to about 10% of the Mk.II series ejections in 1954 [14]

Attention soon focused, however, on the parameters of emergency egress wherein the Mk.II series seats still fell short. Two of these were in high-speed and low altitude situations. Changes in the ejection gun ensued which increased ejection trajectory without significantly increasing peak acceleration. Additionally, the adoption of a two-stage drogue chute design resulted in faster, quicker and safer deployment of the pilot's personal parachute at higher speeds. Finally, in order to prevent lower extremity flail injury, which frequently were a consequence of high-speed ejections, a system was devised using nylon strap restraints to secure the legs to the seat on actuation where they were secured until the man-seat separation occurred. These modifications resulted in a system which allowed successful ejection from altitudes of 50 feet altitude and 130 knots IAS. The new system was designated the Mk.III series seat.

Further modifications were carried out on the Mk.III series seat over the next few years to achieve a further refinement in the parachute deployment process (primarily a reduction in the drogue/mainchute deployment sequence timing), which resulted in successful ejections from zero altitude and 90 knots IAS. The seat was also tested in ejections above 40,000 feet which proved that the seat was usable in both extreme polar limits of the possible performance parameters.

In the same time period (1954 through 1955), a system was devised whereby automatic explosive canopy jettison was incorporated as part of the seat actuation protocol, so that no time was wasted in clearing the canopy before egress was initiated. Owing to possible complications, however, the Martin-Baker seats were capable of ejecting through the canopy of aircraft if necessary, and in some RAF aircraft the egress drill was standardised to blast through the canopy routinely (an example in point was the *Canberra* B Mk.II aircraft).

By the time the mid-1950s had arrived, the continuing evolution of the standard British Martin-Baker emergency egress system had enabled the Martin-Baker seats to prove their sound and carefully considered design handsomely, and this fact was not overlooked by many of the other nations around the world who were growing increasingly interested in providing adequate emergency escape for their air force personnel flying high-performance machines.

FURTHER REFINEMENT AND IMPROVEMENT OUTSIDE THE UK

Although Germany’s involvement in aircraft egress systems had come to an end with the conclusion of the Second World War, the other early pioneering nation in ejection seat design--Sweden--continued to evolve their indigenous egress system engineering.

With development of the SAAB J32 *Lanson* interceptor/strike aircraft, a two-seat machine which flew for the first time in 1952, a new requirement arose for an ejectable seat system. This resulted in the 101 pound SAAB Type 3 (Type 32) ejection seat, powered by a two-stage explosive cartridge gun, and featuring the standard pilot-worn back-style personal parachute and seat-stowed survival kit as the in the previous seat (Type 29). Whereas the Type 29 seat had weighed about 66 pounds and was capable of being used at an altitude of 300 feet in level flight, minimum altitude for safe ejection using the SAAB Type 32 seat was reported to be about 150 feet in level flight. The Type 32 seat also featured separate guide rails (as in the Martin-Baker seat design) and a specially shaped parachute canopy; the seat survival kit incorporated a hard-shell container for the first time, instead of a soft-pack, thereby helping reduce acceleration overshoot potential. An inertia reel restraint system was also added, as was a modification from guide rail rollers to slide bars, an innovation that enhanced smoothness of operation. Seat actuation was again initiated by either use of the a face blind or a secondary "grab-loop" situated on the seat between the occupant’s knees.

In 1949 SAAB began studies which would result in the development of an entirely new design for a supersonic, delta-winged interceptor aircraft, capable of speeds in the vicinity of Mach 1.5 to Mach 2, to be designated the SAAB J35 *Draken*. In view of the rather small cross section selected for the new design so as to insure sufficiently favorable drag characteristics favorable for supersonic flight, the cockpit's dimensions would have to be carefully considered in development of a suitable ejection seat system. [Interestingly, while the Swedish aeronautical engineers quickly focused on this critical concern--supersonic drag coefficients as related to cross section--their Convair colleagues in the United States who were developing the new delta-winged American interceptors (XF102) initially did not, and it was only after incorporation of Whitcomb's "Area Rule" formula that the American delta design achieved a modicum of its anticipated performance capabilities.]

In order to comply with the requirement for a low profile cross-section, it was decided that an entirely new seat would have to be developed. This new seat was again explosive cartridge driven and was installed on the first of the new SAAB J35 *Draken* delta-winged aircraft, which flew initially in October of 1955. The Type 35 seat featured a back-style parachute, again not integrated to the seat but worn by the pilot, and a seat-pan survival kit of rigid design. The seat was actuated either by the conventional head-blind device or a secondary actuator located on the lower seat, and had a dampening feature built in to help absorb crash-landing forces as well as an adjustable seat pan. Harness and deployment mechanisms were virtually the same as those used on the preceding Type 32 seat, and installation of the seat was made on a slight rearward cant (similar to the 30 degree rearward angle found on the SAAB J29 aircraft).

Sometime later, the SAAB J35 *Draken* F model was fitted with the new SAAB 35 *Draken* Rocket Seat Escape System. This new generation egress design replaced the conventional explosive catapult gun with a 5-nozzle cylindrical rocket motor fitted under the seat pan, as in the later Martin-Baker rocket seats. Firing of the 4.4 pound rocket charge was accomplished by generation of pressure in the catapult gun, and total burn time was about 0.2 seconds. While the original (non-rocket) *Draken* seat weighed about 176 pounds, the new rocket powered version totaled about 222 pounds (this included all components, chutes, kits, etc.), and substantial revisions of the rocket-equipped J35 seat included doing away with the face-blind actuation device in favor of a lower, pan-mounted ejection handle, and installation of automatic leg restraining straps. Additionally, the new rocket powered seat required installation of a new type of drogue for stabilisation control.

Fully automatic in egress sequencing from initial actuation, the rocket system allowed true zero/zero ejection capability for *Draken* fighter aircrewmen, and the new rocket seat was retrofitted to all earlier J35 *Draken* models. In 1967 the next generation SAAB J37 *Viggen* interceptor first flew, and a slightly improved version of the SAAB rocket seat was fitted to it. Understandably, use of the SAAB rocket seat in operational employment has provided much valuable data on the system, which has been constantly improved and evolved by SAAB.

Although the SAAB seat system was not selected for installation on the latest Swedish aircraft design, the JAS39 *Gripen* (The Martin-Baker Mk.XL system was chosen), there is no question concerning the excellence of Sweden's past and present contributions to aircrew egress systems development, from its earliest products through the latest (and last). So well engineered and maintained are the now more than 40 year old *Drakens*, and their internal systems (including the egress system), that in Finland, one nation which uses the *Draken*, the Finnish Satakunta Air Wing's *Drakens* have never had to use the SAAB egress system in an emergency. Unfortunately, the pioneering research accomplished by SAAB in the field of egress systems from the late 1930s onwards is many times not fully acknowledged or recognized as today's advances in system technology continue to overshadow previous standards of excellence. For those specialists in this critical area of aviation design, however, the facts peak loudly and eloquently for the engineering capabilities of the SAAB-Scania Aircraft Company, as they shall continue to in the years ahead.

DEVELOPMENT CONTINUES: THE UNITED STATES

Work in the field of military aircraft emergency egress systems in the United States had begun in earnest, as previously referenced, with the revelation of captured German egress documentation painstakingly gathered by the Heinkel Company and the Luftwaffe's Aviation Medicine branch since before the war. However, a complication in the process which was largely absent in the United Kingdom was the intensely political rivalry which existed between the US Air Force and the US Naval Aviation. Ever since the growing importance of US air power in the war had propelled the US Army Air Force further along on its avowed quest to become a fully separate and equal military service within the War Department, there had been corresponding exacerbation of the existing contest between the Army Air Force and the Navy to gain the upper hand in military aeronautical ascendancy. This intense inter-service struggle to surpass the efforts of the other was strongly in evidence in almost every aspect of operational development as well as in research and experimental areas of investigation. In brief, each service argued that it ought to be given the overall supreme authority to develop the nation's potentially awesome aeronautical strength.

Nowhere was this rivalry more in evidence than in the field of aeronautical research and development, and both services maintained distinctly separate research and development commands (in 1947 the US Navy's worst fears were realised when the US Army's Air Force was granted separate and autonomous peerage within the Defense Department as the US Air Force). The political battles which were continually being waged in the US Congress for funding of military projects were clearly polarised between Air Force and Naval Air Arm proponents in just about every category. This included ancillary but no less important areas such as air crew life support and egress. Fueled to a significant degree by this antagonistic atmosphere, it is not much of a mystery that egress research and development schools in both services inherently tended to diverge even more sharply from each other. Of further, and undoubtedly greater importance were the diverging performance criteria maintained by each service regarding ejection seat operational parameters. The US Navy insisted that naval aircraft needed a fully developed low-level ejection performance, reflecting safety concerns for the intrinsically hazardous nature of carrier operations. The US Air Force, by contrast, felt that safe ejection capability below 500 feet was unrealistic (not survivable, statistically speaking) and therefore unimportant as a procurement objective. Adding further impetus to this Air Force view was its awareness of the coming importance of the high-altitude interception role, which would increase with escalation of a Cold War hostile penetration treat posed by high and fast flying Soviet intercontinental bombers.

Immediately after the war had ended, the US Navy had shown a great interest in the work being carried out by the Martin-Baker Company on aircraft ejection systems. The US Army Air Force, in contrast, maintained the opinion that the development of ejection seat systems ought properly to be undertaken by American aviation companies in cooperation with the US Army Air Force's Air Research and Development Command (ARDC) at Wright Field (soon to become the Wright-Patterson AFB Air Development Center). The consequence of this veering away from each other's inflexible contention was that US Air Force airplanes ultimately were developed with a range of different and proprietary US designed ejection systems, while the US Navy's aircraft for the most part, initially used systems at least heavily influenced by the English designs and ultimately incorporating specially modified and uniformly adopted Martin-Baker systems after experience with US systems proved not fully suited to low-level ejection requirements (i.e. carrier operations) .

As previously mentioned, In October of 1945, US Naval officers J.J. Ide and R.B. Barnes had visited the Martin-Baker works at Denham to investigate the M-B test program and witness ejection seat trials. Subsequent to the visit, and after completing an assessment of suitable types of research equipment intended for ejection seat testing, the US Navy ordered a 105 foot seat testing tower to be installed at the Navy Yard in Philadelphia and for an actual example of the Martin-Baker Mk.I seat for purposes of testing it in a naval aircraft. Less than a year after the installation an initial test shot was undertaken, followed shortly thereafter by the first live seat test (August 1946). From that time forward, over the ensuing few years, a great deal of intensive physiological investigation was accomplished by the US Navy on ejection seat operational parameters and this was further advanced by numerous studies undertaken on Martin-Baker ejection seats installed in a modified Grumman F9F *Cougar* in 1957. Despite reluctance of the Grumman Company to participate in the tests, the results were quite satisfactory and the US Navy/Martin-Baker bond was further strengthened. The Navy approached the Martin-Baker Company in this matter of fitting a special Martin-Baker seat to replace the Grumman seat in the Cougar with a mind to adopting the English seat for all its carrier-based aircraft. The tests were quite successful and this resulted in the development of the Martin-Baker Mk.V seat specifically for US Navy use, which was widely used in variant applications in the F9F-6, the F-4, the A-6, and several other Navy aircraft. The Mk.V was produced alongside the Mk.IV, but differed in that it (the Mk.V) had been specially strengthened to decellerative G limits well beyond that engineered into the Mk.IV seat (40 Gs vs. 25 Gs). The Navy Mk. IV seat also incorporated a crotch loop pull handle actuator for the first time, as it had been found that in certain instances involving sustained high-G force, a pilot sometimes could not reach his arms above his head to grab the face-blind actuator to eject. The crotch level pull-loop provided ejection actuation capability for both possible scenarios.

Meanwhile, the US Air Force’s Wright Air Development Center was developing a concern, in the mid-1950s, over how to best configure a suitable high-performance ejection system for the latest supersonic members of its new "Century Series" aircraft. American developed ejection seats had been produced by the North American, Douglas, Republic, Lockheed, Grumman, Weber, Stanley, and Stencil companies, and US Air Force aircraft had come into production in the early 50s with these seats. Most were actuated by arm-rest type triggers and were intended to work with the standard US Air Force back-type personal parachute, but none provided even a vestige of zero/zero capability and few indeed assured a safe ejection below the 500 foot altitude selected by the Air Force originally as the minimum safe low-level performance parameter. Of the many designs in use on Air Force aircraft, the Douglas ESCAPAC seat purportedly had the best reputation and would later almost match Martin-Baker performance standards, statistically speaking (the Douglas ESCAPAC 1A system was originally developed for use in the US Navy's A4 *Skyhawk;* it proved so effective that the Escapac 1A system served as the developmental basis for a whole collection of successive evolutions of this basic design that ultimately culminated in today's McD/D ACES II system).

One of the reasons the Air Force apparently initially abandoned study of low-level ejection systems was the opinion that extant seat catapult forces generated by systems in use on its planes could not generate the high forces needed to lift the aircrew high enough above the ground to allow full parachute deployment in low level egress situations.. The Air Force maintained that a limit of 22 Gs of vertical acceleration were the human physiological ceiling for safe ejection. Curiously, this figure seems to coincide with the final criteria developed by Germany in its early (WWII) studies of allowable vertical ejection acceleration forces, but it contrasted strongly to the vertical G limits of the Martin-Baker seats being tested at that time (about 32 Gs). Further, with Mach 2+ aircraft such as the Convair F106 *Delta Dart* under development, another concern expressed itself in how to engineer a high-performance seat that would allow routinely safe supersonic ejection. The development of a whole new generation of post-war, high performance jet aircraft (soon to be known as 'The Century Series'), would spur interest in the swift development of a functionally adequate USAF ejection seat with capability for safe ejection well in excess of the speed of sound.

These problems were soon to be investigated at Edwards Flight Test Center in California, Holloman AFB in New Mexico, and on Hurricane Mesa in Utah, using high speed rocket-powered sleds in a series of ongoing investigations which were ultimately intended to produce what the Air Force termed perhaps too simply the *"Supersonic Seat"*.

It was recognized that one likely way of providing the necessary power to successfully meet the demanding parameters of human physiological limits, while simultaneously satisfying the ejection systems physics requirements, was through the use of staged rocket motors incorporated into the seats. In October of 1957 a requirement was specified by the US Air Force for a satisfactory supersonic-rated ejection seat system which would provide high-speed egress as well as adequate and reasonably safe low-level ejection (although this was still suborned to the high speed/high altitude capability requirement). This was termed the USAF / ICESC (Industry Crew Escape System Committee) program, and a committee of major US aviation firms was jointly established with the Air Force Systems Command to develop the system. Two proposals for a system meeting all requirements were considered, an "A" proposal and a "B" proposal. The Convair Company (formerly Consolidated Vultee) was finally given the go-ahead under the aegis of the ICESC to undertake primary project development of its "B Seat" design proposal, with the Stanley Aviation Company as a partner. The ICESC studies involved over 6 years of intensive testing (1 January 1956 through 30 June 1961) of the Convair / ICESC "B" Seat System on the high-speed rocket sled tracks at Edwards and Holloman. These rigorous and extensive tests ultimately culminated in the live ejection of volunteer TSgt. James A. Howell from the specially modified Convair F106B (two seater) aircraft at an altitude of 7113 meters and an IAS of 800 kph. The Convair / ICESC "B" Seat featured a unique, tilt-articulated design which upon actuation would first elevate the seat into a backwards-tilted horizontal plane (with pilot in supine position) above the aircraft’s cockpit, before firing the seat’s rocket motor to blast the occupant clear of the plane. The seat’s appearance was distinctive in that, when deployed, the seat pan’s convex bottom extended beyond the feet of the aircrewman, which were first drawn up tightly towards his chest in a foetal position, so as to protect him from supersonic wind-blast effects.

The B Seat (other slang terms for the seat included the 'Tilt Seat', the 'Rotation Seat', and 'Supersonic Seat') was a strangely appearing design, with twin survival kit components sited bilaterally along the sides of the seat's occupant, and ejection actuator D-ring situated at crotch level. Featuring an integrated shoulder/lap harness, upward rotating 'sugar scoop' foot pans, powered foot retraction spurs, bilateral thigh guards that pulled the knees up towards the chest, aneroid controlled drag and recovery chutes, and two gas operated telescoping stabilisation booms that projected aft on actuation, the seat not only looked strange but certainly must have presented the rider with a unique (possibly) terrifying prospect as he was first shot upwards into the wind at supersonic speed, then slammed back into a supine position before being fired away from his stricken aircraft with a powerful rocket blast. The seat was secured to the rotation frame with 4 explosive bolts that blew just before the rocket fired.

The B Seat ejection sequence was essentially as follows: A pull on the D-ring jettisoned the canopy, tripped the AFCWS (automatic flight control system) disconnect switch, retracted and locked the shoulder harness, retracted the occupant's feet via cable connected power reel spurs, raised the foot pans and elevated the occupant's knees and thigh guards. Feet retraction and canopy jettison safety locks release, allowing further pull on the D-ring, which disconnected the seat actuator and fired the seat's vertical thruster, moving the seat up the rails and out into the slip-stream. At this point the hose disconnect and personal-leads disconnect separated and at the end of the vertical thrust stroke, two rotational thrusters fired, slamming the pilot into a supine (horizontal) position above the aircraft's fuselage. During this rotation, the gas operated stabilisation booms were extended and the four break-away bolts were fired. At this moment the primary escape rocket would fire the seat and occupant away from the aircraft. Two modes of chute deployment provided full deployment in low speed/low altitude mode at three and a half seconds, and full deployment at high speed in four and three quarters seconds. At extremely high altitudes, the pilot would stay with the seat until a safe lower altitude had been regained. The total weight of the seat and occupant, fitted with all normal personal equipment, was a substantial 607 pounds!

Although tested extensively in at least 15 rocket sled tests and 11 test flights (using an F106B two-seater), the single high altitude human 'live-fire' test was accomplished at 22,580 feet and only Mach .77 (at that altitude); flight performance parameters at the time of the test were far in excess of more realistic suboptimal conditions and did not come anywhere near the 'hard corners' of the seat's anticipated performance envelope. Rocket sled tests were exhaustively run on the test track with instrumented dummies at speeds simulating Mach 2.5 at a simulated altitude of 9,700 meters, with satisfactory results. Additionally, 35 human test subject rocket sled runs were reportedly concluded, verifying that ejections up to 900 knots IAS were within the range of human endurance.

As a result of the successful tests, the Convair / ICESC "B" Seat, or "Tilt-seat" as it became more commonly known by life support and human factors specialists, was installed in all production block Mach 2+ rated F106A & B aircraft--the most formidable and most high performance of the US Air Force's vaunted "Century Series" aircraft of the late 50s and 60s--from 1957 through 1959.

Unfortunately, and in spite of the years of exhaustive testing carried out in its development, the Convair / ICESC Tilt-seat did not prove satisfactory in actual Air Force operational use; this was especially true in the less favorable corners of the projected envelope. As might be predicted, the marginally assured low-level, low speed performance of the controversial seat simply did not meet minimal requirements...especially under anything less than optimal conditions. After several fatalities occurred during F-106 emergency ejections involving use of the Tilt-seat, a decision was made to remove the seat and replace it with a conventional, rocket-powered seat design made by the Weber Corporation. This retrofitting of the *Delta Dart* with the Weber seat was accomplished in 1963; thereafter, the Weber seat egress system remained in the delta-winged F106 for the rest of its 30 year service life and provided satisfactory high-speed ejection as well as adequate zero/zero capability.

Possibly as a consequence of the ultimate failure of the Air Force's ICESC supersonic seat program, the decision to use Martin-Baker designed seats in the Air Force version of the McDonnell-Douglas F4 *Phantom II* was a bit less objectionable in the years to come, and especially owing to its already proven performance. In any event, it is fascinating to speculate on this.

To return to the US Navy's growing post-war association with the Martin-Baker Company, formerly alluded to, the Navy was by now also investigating the use of rocket engines as a satisfactory means of propelling a seat clear of a stricken naval aircraft without incurring unacceptable ejection injuries in its personnel. Studies conducted with the catapult gun then in use indicated that even significantly enhancing the conventional gun's charge would not produce the desired Naval requirement for "dirty" low-level escape. Consequent to this, the Navy authorized the development of a rocket motor capable of being used on existing American egress system seats. A lengthy series of tests were conducted at the China Lake Naval Ordinance Test Station (NOTS, as it was then designated) on its high speed rocket sled track, and this eventually resulted in the production of the RAPEC (Rocket Assisted Personnel Ejection Catapult) system. Tests continued, concurrently, with the Martin-Baker ejection system at the US Naval Flight Test Facility in Patuxent River, Ohio.

By this time, the Douglas and Vought aircraft companies had devised rocket powered seats which were in the research and development phase. Both appeared to be capable of meeting Naval emergency ejection requirements at a lower limit of 150 feet altitude and 150 knots IAS--still not satisfactory parameters for the stringent zero/zero emergency requirements desired by the Navy. At this point, the political nuances of the competing systems manufacturers' battles to secure Naval procurement contracts intensified considerably, and the result was a compromise in which the Douglas Escapac RAPEC system was selected for use in the Douglas A-4 *Skyhawk*, while Martin-Baker was selected to provide a uniform system for use in the remainder of US Navy aircraft. This final decision was still complicated further by an exception to the agreement which allowed North American Aviation to provide its own seat for use in the RA-5 (A3J) *Vigilante* and one other aircraft. Furthermore, a concurrent program authorized use of the Stanley built RAPEC seat in the Martin P6M jet-powered seaplane patrol bomber, due to inadequacies existing in the aircraft's original seat system. Subsequent emergency ejections involving an unmodified P6M and a later, RAPEC configured version, confirmed the effectiveness of the new RAPEC system.

In operational use, the Douglas Escapac HS-1 and LS-1 RAPEC seats used in the RA-5 (A3J) and T-2 aircraft proved their effectiveness in several incidents involving successful non-combat egress in the RA-5 (A3J) *Vigilante* at and above the speed of sound, and during the Vietnam conflict, Douglas HS-1 Escapac RAPEC type seats in the A-5 routinely allowed aircrew to successfully eject above the speed of sound in emergency combat ejections involving that type (25% of the combat RA-5/A3J ejections were undertaken above Mach I).

With the withdrawal of the RA-5 *Vigilante* from active operational use in the late 1970s, the only American rocket powered open (non-encapsulated) escape system proven in use for successful Mach 1+ recovery, and capable of zero/zero to 700 knots IAS performance, was also retired (this was a North American Aviation design), excluding the special X-15 seat system (also a North American design) and the Stanley/Lockheed S/R-1 system used in the Lockheed SR-71 *Blackbird* aircraft.

Meanwhile, development in both the US Air Force and the US Navy continued apace as new aircraft with different performance parameters came into service. One type of advanced concept ejection system which found its way into at least two supersonic, multi-engine designs was the fully encapsulated aircrew escape system. A version built by the Stanley company was installed on the Mach 2 Convair B-58 *Hustler*, a strategic nuclear bomber of amazingly high performance for its time (originally flown in the early 1960s). The 558 pound capsule, which unfortunately had a relatively high failure rate, was designed to provide flotation in the event of a water landing, and upon ejection streamed the half-open recovery parachute for 2 seconds to slow forward speed before reef cutting devices automatically allowed the 41 foot ring-sail type chute to fully open. The B-58 capsule featured upper and lower frontal clam-shell doors, which would close and seal in an emergency. The capsules featured self-contained individual oxygen and pressurisation systems, much like another, later design, engineered by the North American Aviation company and installed in its Mach 3, advanced strategic bomber prototype, the XB-70 Valkyrie. The Valkyrie's encapsulated system was the only one of its general design to have been fully flight tested and approved prior to completion of the XB-70 aircraft itself. Another system, based upon the ejectable crew cockpit design (which harked back to the original ejectable crew-section concept used in both the WWII era Bachem Ba 349 *Natter* and Heinkel He-176), was developed for the controversial American TFX swing-wing aircraft. The TFX aircraft, after a prolonged and difficulty-laden initial development which called for its being adopted by both the US Air Force and the US Navy in slightly differing versions, would ultimately outgrow its teething problems and evolve into the excellent US Air Force F-111 Aardvaark fighter-bomber.

Returning, for a moment to the early part of the 1950s, it is interesting to reflect for a moment on the concept of the American downward-firing ejection seat system. In particular, the Lockheed Company, in developing its powerful but lightweight F104 Starfighter in response to requirements provoked by experiences derived from aerial combat in the Korean War, elected to incorporate a downward firing pilot's ejection system in the unltra-compact crew section of that post early 1950s design. As the inherent hazards of downward ejecting seat configuration are readily apparent, Lockheed's decision provokes speculation that the official US Air Force's consensus that ejections below 500 feet were not essentially survivable may have had inordinate impact on this aspect of the Starfighter's development. There were Lockheed engineers who believed that, owing to the great speeds which the aircraft was designed to fly at, an upward firing system using the existing seat catapult technology would not be able to clear the F104's tail assembly in supersonic flight. There were certainly also numerous critics of the downward ejection scheme at that time, but the preponderant opinion that successful upward ejection was not absolutely attainable with existing technology managed to sweep these objections aside and work continued using the downward ejecting seat design.

Lockheed, in partly addressing critics of the system, suggested emergency procedures which would partly offset the hazards of egress situations occurring below 500 feet. Among these were the recommendation that in the event of a low-level emergency requiring ejection, the pilot of the Starfighter was to roll the aircraft 90 to 180 degrees or more to either side before ejecting. This would then yield, at least in theory, a horizontal or inverted vertical upwards ejection trajectory for pilot and seat, rather than a vertical descent. The suggestion was more euphemistic than practical, for in situations involving sudden loss of power, hydraulics or flight controls, such a maneuver would be near impossible to achieve. Further, the small cross section of the Starfighter allowed very little room for the crew compartment, and it was determined that there simply was not enough room in the by-then frozen design configuration to re-engineer a cockpit which would allow for installation of a conventional upward firing system without a major (and costly) redesign. Pilots, who could relate to such possibilities as low-level emergency bailout far more readily than could engineers, viewed the downwards firing system with obvious disapprobation.

The Starfighter prototype, as well as all developmental pre-production and initial production models, had the Lockheed downward firing seat installed. Egress was achieved through a large rectangular hatch located directly below the cockpit. In the event of an emergency requiring ejection, the between the knees actuator handle was pulled first, which set off the following sequential events: 1) the cabin was depressurised, and the control stick stowed forward, clear of the seat; 2) the pilot's parachute harness tightened automatically, just as did the arm restraint net which secured his arms; 3) the pilot's feet where drawn back into the seat's footrests through use of cable attached spurs on his boots; 4) the hatch was blown off automatically, and the seat was ejected straight down with a conventional explosive catapult charge. For clear-thinking individuals, unencumbered by the policy constraints of a manufacturer's cost projections, this system was purely and simply an accident waiting to happen; especially so, in view of the problems that early 1950s high-performance aircraft frequently had with power failure, compressor stalls and flame-outs, and the particular hazards normally implicit in landing and take-off portions of the flight envelope. Although adjudged satisfactory for medium to high altitude use, the original downward firing system was completely useless for low-level emergencies.

Unfortunately, it took the death of a high-profile and very popular flight test pilot to spur a major revision of the Starfighter's egress design. Capt. Ivan C. Kincheloe, blonde, handsome and personable, as well as a highly regarded and high-profile flight test pilot, experienced an in-flight emergency in his production F104A Starfighter in 1958 shortly after takeoff at Edwards AFB in California. His ejection in the Stanley B-1 downward firing seat fitted to his aircraft successfully removed him from the stricken aircraft in a sideways, horizontal plane, as recommended by Lockheed; ironically, however, the aircraft banked and came down shortly after he ejected, exploding in a fireball on the ground which Captain Kincheloe was carried directly into by the ejection trajectory. Kincheloe's death accomplished what a previous ground-swell of earlier protests had failed to do: shortly afterwards the F104 fleet was grounded, the old B, C, and C-1 seats removed, and quickly retrofitted with a Lockheed designed upward firing seat designated the C-2 Seat. Incorporation of the new C-2 seat increased aircrew confidence in the new fighter. At a later date (after 1966) the initial Lockheed designed upward firing seat was replaced by an improved upward firing version of the C-2 seat, designated the S/R-2 seat. This seat was reported to offer near zero/zero ejection capability. All European, export, and later generation Starfighter variants had their American upward-firing seat replaced with a Martin Baker Mk.VII series seat specially engineered for the *Starfighter*, designated the M-B Mk.DQ-7 model. The new Martin-Baker *Starfighter* seat unexpectedly experienced some initial problems, however, and several German Luftwaffe pilots were killed in *Starfighter* ejections using M-B Mk.DQ-7 seat. An investigation team was quickly brought into determine the source of the seat failure and found that frequently the pilot's knees would not clear the forward canopy edge due to the fact that the parachute placement positioned the pilot too far forward. The seat was subsequently modified to address this problem and from then on the Martin-Baker Mk. GQ-7F seat performed quite well in *Starfighter* emergencies experienced by the German Luftwaffe. The same GQ-7F seat was installed in all export *Starfighter* seats the Danish Air Force and other NATO countries were taking delivery of and there were no further difficulties. It is indeed well that that was the case, since the F104 remained a demanding machine to fly throughout its long NATO service life owing to the peculiarities of its high wing-loading, high-performance design, and the training dissimilarities between the American west, where European pilots were trained to use the aircraft under typically excellent conditions and the European region with its usually marginal weather.

Among the refinements added to American-made seats of the mid-50s were inertial-locking harnesses and seat-pilot separation mechanisms (the seat-man separator on US Air Force seats consisted of a strap arrangement fitted between the seat and the pilot’s rear seat cushion, or parachute pack, which was sequenced to actuate after ejection had occurred and simultaneous with seat restraint release), after studies indicated that a more positive man-seat separation action was required to get the aircrewman away from the ejected seat. Thigh restraining guards were usually fitted and folded away in the down position until the seat was fired, being raised for use along with the armrest ejection triggers which were a standard American feature. In some cases, leg restraining mechanisms were also fitted, as in the original F-104 *Starfighter* seats.

In the early 1960s, North American Aviation experimented with a series of lightweight seat systems termed the "LW" series. This resulted in an LW-1, an LW-2 (developed for the XV-19 experimental aircraft), and a final LW-3 seat that was produced for use in its twin prop driven OV-10A Bronco forward air control / armed reconnaissance plane. The seat was designated the LW-3B model and two were fitted, fore and aft, in the Bronco’s cockpit. Uncharacteristic of the trend at that time, the LW-3B seat featured a seat-mounted pilot personal chute in an unusual configuration. The aircrewman’s parachute was fitted to the side of the seat, housed in an elongated rectangular pack, and the system was capable of near zero/zero performance. In view of the fore and after seating arrangement of the OV-10A, the seats were angled to fire slightly to the side and away from each other, with the rear seat sequenced to eject first in the accustomed manner. The LW-3B type seat was later installed in the experimental prototype VTOL XV-15 tilt-rotor aircraft for flight testing of that machine in a tandem arrangement, and has also been installed more recently in civilian turbo-Mustang (F-51) conversions such as the Cavalier II, where it provides emergency ejection capability in a confined cockpit structure. The LW-3B seat featured a standard hard-shell seat type survival kit (RSSK 9) under the seat cushion. This was the first American seat to presage the future trend of installing the pilot’s personal parachute on the seat itself (although modern seats feature the chute assembly in the seat’s headrest area, not fitted to the side of the seat as was the case with the LW-3B). Reports of the Bronco system in use indicate it had a satisfactory success rate in combat situations (Vietnam), both for low level and medium level ejection.

It must be noted in passing that although American systems had originated from studies based upon the German escape technology of World War Two, there were several features incorporated in them which were thoughtfully conceived and engineered. One of these was the locking inertia-reel harness, which is to be found on nearly all American manufactured seats produced in the early 1950s (each of the 1950s Century Series fighters featured this device). Another is the life-support quick disconnect block, again incorporated in virtually every system produced by the US in this period. This latter device featured a module, frequently affixed securely to the seat, into which the aircraft and pilot connections were inserted for G-suit, breathing oxygen and communications use. Upon ejection, the aircraft connectors would pull free, leaving the seat-portion attached, from which the pilot’s connections would be released at the time of man-seat separation. Similar systems were not incorporated into Martin-Baker seats until the advent of later M-B Mk.IV models.

Several other systems were investigated that involved a pseudo-podded escape concept. One of these proposals was a design that featured inclusion of the aircraft's canopy as a sort of protective enclosure, with the pilot being drawn upwards into a supine position under it before actuation (this was researched for initial use on the Convair F102 *Delta Dagger*, but discarded in favor of a conventional Weber rocket seat). The canopy, with the pilot enclosed under it, would then be fired away from the aircraft. This concept was discarded after some initial exploration into its suitability.

Of passing interest is the fact that while the idea of the crew 'escape pod' was not entirely new, having been first actively explored in German designs of the early 40s (notably in the He-176 rocket powered aircraft), its possibilities were being closely studied in the late 40s and early 50s by US aeronautical and egress scientists. While US aircraft engineers subsequently designed several systems that would be incorporated into high performance aircraft of the 50s and 60s, in a curious footnote to this inovation, a little known Humphrey Bogart film titled 'CHAIN LIGHTNING' that came out in 1950 featured the escape pod idea with a central role in the plot (along with a primitive high altitude pressure suit). Although the technology represented was rude and almost laughable, by today's standards and in terms of what we now know about such highly sophisticated systems, the basic concept was amazingly all there. This old Bogy film is worth seeing for this and Hollywood's 1950s pressure suit representation, although the story line itself is considerably dated.

In the early to mid-1950s, a considerably advanced Mach 3.7 high altitude, point/area defense air interceptor aircraft design was proposed by Republic Aviation. This was what came to be known as the XF-103 (USAF Secret Project MX-1787), which never saw production (it was cancelled in 1957), but which took form in a completed full-scale engineering mock-up. This futuristic appearing interceptor featured an unusual 'boot-shaped' crew pod, in which the pilot of the XF-103 could encapsulate and eject downward. Preliminary studies showed the pod to be unusually aerodynamically stable, despite its odd appearance, but the system was never actually tested. The XF-103 pod promised to allow aircrew escape at the upper limits of the aircraft's performance envelope, although data was never released concerning its low altitude, low speed characteristics (presumable very poor, given experience with other downward firing systems in use at the time in similar operating conditions). This concept did, however, pioneer certain parameters shared with later upward firing podded escape systems that would be used successfully in the B-58 Hustler and XB-70 Valkyrie .

One instance of a very satisfactory American escape system having been developed is found in the ejectable crew compartment concept employed in the General Dynamics F-111 *Aardvark*. Although a controversial design from its very onset, the F-111 (neé TFX), with its swept-wing features and technical innovations, featured an egress system which was one of the most reliable component systems found on the plane. Borrowing from pioneering studies conducted by the Heinkel company and use of the concept in its He-176 rocket-powered airplane of WWII vintage, the General Dynamics Corporation (formerly Convair) incorporated an ejectable crew compartment egress system in the final pre-production TFX prototypes. Although the original prototype had flown using two conventional ejection seats, the ejectable crew compartment became a standard feature of the F-111, and throughout its service life provided *Aardvark* crews with reliable, safe egress--both in non-combat emergencies as well as in wartime combat situations (Vietnam). As might be imagine, the ejection sequence involved actuation of an explosive disconnect system which separated the crew compartment from the nose section and fired a rocket system which shot the crew section away from the crippled aircraft. A high-speed drogue system then deployed, which in turn actuated a recovery parachute attached to the compartment. Crew members had the choice of either staying in the capsule until it came down to earth or opening the canopy and manually parachuting from the compartment while it was still descending. Statistically, the success rate of F-111 ejections was remarkably high, testifying to the engineering concept and development underlying the design.

It is worth noting, in passing, that the Bell X-2 rocket research aircraft that was being flight tested in the mid 1950s at the Edwards Flight Test Center in California featured a jettisonable crew compartment. The plane was designed to exceed Mach 2 at a time when such extreme speeds by manned aircraft were still challenging, and as yet unreached, aeronautical objectives beckoning to aviation engineers. Interestingly, on September 27, 1956, Captain Milburn Apt was flying the 13th test flight of the Bell X-2 when he encountered a particularly severe roll-coupling situation in flight testing at a speed of Mach 3, after beginning a descent from 72,000 feet. So unusual was the situation, and so severe the buffeting which resulted that the decision was made by Apt to eject, and he did do, actuating separation of the entire nose section of the research aircraft which contained the small cockpit. The capsule was designed to be separated, then stabilised by a drogue chute after adequate deceleration had occurred. Once the capsule's recovery chute had been deployed, the plan was for the occupant to release the canopy, unstrap his harness and manually bail out using the capsule's seat-type personal parachute.

Documentation of the accident shows that the capsule separation was achieved as planned for and that the drogue system worked as anticipated. Unfortunately, Apt appears to have been disabled through some sort of injury sustained, either in the violent buffeting before ejection occurred or after the capsule separation took place, and was unable to leave the capsule before it plummeted into the desert floor at about 120 mph. The G forces sustained in the impact, estimated to be about 90 G (plus or minus 40 G), resulted in Apt's death. The Bell X-2's recovery capsule was not intended to land with the pilot in it, unlike other systems (such as the F-111) in which emergency descents might be survived while still contained within the capsule's crew compartment. Evidence was found at the site which indicated that Apt had succeeded in jettisoning the capsule's canopy, and also had been able to release his restraint harness prior to impact, but had not been able to leave the capsule to bail out of it for reasons which are still uncertain.

Although the North American XB-70 supersonic advanced strategic bomber program never progressed beyond the production of two prototypes, the crew escape system that consisted of fully encapsulating individual crew modules was inadvertently put to the test in an unfortunate mid-air accident which destroyed the number two XB-70 prototype (XB-70A-2) on 8 June 1966. As designed, the individual capsule-type crew ejection system allowed for safe ejection from near zero/zero conditions (90 knots IAS, zero altitude) through Mach 3 and its 80,000 feet operating ceiling. Each module consisted of a central seat unit which employed upper and lower clam-shell type doors to cocoon the crew member when the escape system was actuated. Each contained its own environmental support system and allowed for pressurisation and crew oxygen so that in addition to serving as a rocket powered escape vehicle, the capsules could also protect against emergency high-altitude decompression in flight.

A window in the upper clamshell door allowed observation of instruments while the crewman was encapsulated, and provision was made for minimal encapsulated control of the aircraft thusly configured. Ejection sequencing consisted of manual actuation of the arm-rest triggers, immediately whereupon the capsule tilted 20 degrees to the rear before encapsulation by the clam-shell doors was accomplished. Further, the crewman's heels had to be properly emplaced before the process would begin. After the capsule had closed and sealed, the crewman had to activate a further actuator to jettison the upper and lower fuselage before firing the capsule out and away with its integral rocket motor. Main recovery chute was automatically deployed by a complex barostatic system and capsule descent rate was reported to be about 28 feet per second. Twin, rear projecting booms served to stabilise the capsule during ejection and an inflatable cushion automatically deployed (with a manual inflation option) under the capsule to help the occupant withstand landing forces. The crewman remained within the capsule throughout the entire recovery process, from ejection to landing, and included in the capsule were survival equipment, life-raft and other items. On a water entry, the capsule would remain afloat in an upright position automatically.

The prototype XB-70A-1 and A-2 aircraft undergoing flight testing from 1964 through 1969 were configured with two such crew capsules (pilot & copilot), although the intended production B-70 bomber was to have two additional crew positions in routine operational use.

On 8 June of 1966, during a media fly-by flight of several types of aircraft using GE engines (the XB-70 included), an inadvertent mid-air collision occurred involving a Lockheed F104 Starfighter and the number two XB-70 prototype. The cause of the F104's veering into the starboard outer wing section of the XB-70 was never to be learned, although the consequence of the collision was the immediate destruction of the Starfighter and the smashing of the two vertical fins of the XB-70, which the F104 slashed through after hitting the bomber's wingtip.

The XB-70A-2, traveling at about 300 knots IAS, remained in a state of stable horizontal flight for about 16 seconds after the collision before suddenly going into a nose-down roll, with subsequent violent yawing that ended up with the aircraft entering a final, unrecoverable flat-spin before impacting in the desert, 25,000 feet below. The two crew, test pilots White and Cross, immediately upon experiencing the roll over, began to realise that ejection was mandated. Pilot White was successful in ejecting himself by pulling the ring to begin encapsulation, which he estimates he accomplished about 60 seconds after the XB-70A-2 became violently unstable. His copilot, Cross, was apparently unable to do so. It is speculated that possibly G-forces or a head-injury may have prevented him from taking the initial step to initiate ejection. White, meanwhile, caught his arm between the clam-shell closure seals and suffered a dislocated shoulder attempting to free the arm, but managed to get free and was safely lowered to earth in his capsule. Despite the fact that the impact cushion beneath his seat failed to inflate, he survived the 43 G impact, albeit with severe internal injuries that were partly lessened by collapse of the capsule's internal seat structure.

Cross's capsule was never ejected, and its remains were recovered in situ at the site where the XB-70A-2 hit the earth in a flat spinning attitude and burned. The incident was thoroughly investigated from all angles, including performance of the life support/escape system, and White's survival contributed greatly to knowledge of how such an encapsulated escape system could be further engineered to deliver an even higher level of protection. The mere fact of his survival vindicated, at least in part, the integrity of the encapsulation escape system concept.

In still other areas of US military flight operations--particularly in the area of flight test--various escape seat systems were developed for special applications. One of these was the North American Aviation escape seat designed for their X-15 high-altitude, Mach 6 rocket research vehicle. The seat employed was designed and extensively tested--again on the Air Force's rocket sled track at Edwards in California--to allow for escape at extremely high altitude and extreme speed. Considering the performance parameters of the X-15--maximum altitude of more than 50 miles and maximum speeds exceeding 6 times the speed of sound--the challenge was formidable. Once more, a rocket powered, open-seat design was employed, which would allow recoverable egress up to a speed of Mach 4 in any attitude and any altitude up to 120,000 feet. During ground testing on rocket sleds at Edwards Air Force Base, the seat was demonstrated to give good ground-level escape at speeds as low as 90 knots IAS. A ballistic rocket-type catapult system provided the basic propulsion force, and the seat featured side-mounted folding stabilizing fins and extendible booms that would deploy upon ejection to maintain proper escape attitude during initial boost phase of about 0.5 seconds and subsequent recovery deceleration, until the seat drogue system and main recovery chute could release satisfactorily.

Amazingly, despite many years of often quite dangerous flight testing at the very limits of known aerospace performance parameters for manned vehicles, the X-15 ejection seat system was never needed, and hence no documentation exists as to its actual performance in the event of a genuine flight emergency requiring ejection, as none occurred.

Among the more unusual egress systems developed in the US was the Stanley "Yankee" System, in which a tractor rocket was integrated to the pilot's harness which would be fired off to literally haul him out of the aircraft's cockpit. This system, which was fitted to some aircraft in which it would have been impossible install conventional ejection seats, was in use in the mid 1960s and was fitted to the Douglas A-1D *Skyraider*, among others. The system provided for aircrew extraction by rocket first, after which a second rocket deployed and spread the pilot's personal back-style parachute; the Yankee System was successfully employed in a real emergency situation in Vietnam in 1967, when a *Skyraider* piloted by Maj. J.E. Holler sustained engine failure at low level in combat. It is interesting to note that this system provided true zero/zero capability at a time when no other conventional systems did.

Still other innovative egress systems under investigation during the Vietnam conflict were the Karmen Aircraft SAVER System, and the Goodyear Aerospace PARD System. The first design consisted of an ejection seat which after deployment functioned like an autogyro. The Karmen Stowable Aircrew Vehicle Escape Rotoseat (SAVER) contained a small turbojet and folding rotors and tailplane, which would allow the pilot to remain airborne and travel about 50 miles at speeds of about 100 knots. Its development was incomplete when the war ended, thereby ending investigation into its possible use in combat aircraft.

The second egress system mentioned above was the Goodyear Pilot Airborne Recovery Device (PARD), and this system featured an unusual balloon-parachute hybrid design (called a BALUTE) which would fill with heated air provided by a small LPG burner above the pilot's conventional parachute, after ejection in a standard ejection system seat. The heated air would allow the pilot to remain airborne for about 30 minutes, during which time a mid-air recovery attempt could be effected with an aircraft equipped with appropriate snaring apparatus. The system was tested and demonstrated to work successfully in tests performed in Southern California, but again the project was discontinued when America's Vietnam involvement ended in 1975.

REFINING THE ORIGINAL CONCEPT: THE UNITED KINGDOM

As research and development of seat technology gained momentum in the decade following the end of the Second World War, there were at least two other companies involved in production of ejection seat systems for high performance aircraft, in addition to the well established Martin-Baker Aircraft Company. These were the ML Aviation Company and the Folland Aircraft Company, Ltd.

ML Aviation, under the direction of Belgian engineer Marcel Lobelle, produced a series of seats from the ML Mk.I through the ML Mk.IV. The first two seats were fitted into production aircraft in use by the RAF and were manual (not automatic) systems very much like the M-B Mk.I. The Mk.III and Mk.IV were automatic seat designs (fully automated sequencing, with man-seat separation and deployment of personal parachute), but according to B. Philpott were not installed in active service airplanes. The earlier two seats were used experimentally in several aircraft types (including Meteor and Wyvern types) but in 1951 an experimental Hawker fitted with an ML seat crashed, and there was speculation that the pilot's seat had somehow failed. Shortly thereafter the company ceased production of egress systems and focused on other aircraft sub-component manufacturing.

The Folland Aircraft Company of the UK acquired licensing rights to produce the Swedish SAAB Type 29 seat (as fitted to the SAAB J29 aircraft), but modified the system to provide for automatic release before incorporating it into their Folland Gnat, a lightweight, sweptwing fighter/trainer used by India, Finland and a few other nations with some success. Folland was not interested in continuing the production of egress systems, beyond that of the Gnat, and it wasn't long before the only UK egress system manufacturer was the Martin-Baker Aircraft Company.

The Folland Gnat egress seat was a lightweight, simplified system, which suited the perceived need at that time for use of lighter ejection systems for aircraft which were becoming increasingly more complex and much heavier. England's Martin-Baker also felt the need to reduce the weight and bulk of its seat design (the Mk.III) in keeping with this philosophy, and consequently this led to the development of the M-B Mk.IV seat. Naturally, it was important to achieve this weight reduction without significantly altering the level of egress effectiveness which the Martin-Baker systems provided. This was achieved by incorporating a redesign of several key components in the guide-rail/track system and seat framework support structure. The seat pan and parachute pan units were retained with slight modifications, as were the twin-drogue system and the 80 ft/sec ejection gun. The Mk.IV seat incorporated for the first time a between the legs ejection handle as a secondary means of actuation ejection, since it had been determined that in certain situations the effects of adverse inertia and G loading made it difficult to use the conventional face-curtain actuator. (This began subsequent engineering conjecture over the question of whether or not to focus on use of one actuator only, for a number of years, which seems to have ultimately led to final selection of the between-the-legs actuator design as found in the most recent M-B systems).

The parachute and sea-survival/inflatable raft kits were redesigned for use on the new Mk.IV seat, and this was prompted in part by the need to improve pilot comfort as well as fit the overall seat modification requirements. Further improvements consisted of an integrated seat and parachute harness system, eliminating two separate harness systems; the system was controlled by the M-B Timed Release Unit (TRU) and was so effective that it was retrofitted in some cases to older Mk.III seats. The new inverted U-shaped personal chute assembly was placed higher up in the seat back, just under the drogue/head-box container, which positioned it more efficiently for simplified deployment. Sea-survival /inflatable raft--usually made to order by Martin-Baker for the specific requirement of the contracting nation--was stowed in the seat pan, under the pilot, and a specially designed, high-density, slow-acting foam rubber material was used in the seat cushion over the kit to reduce the possibility of spinal injury due to effects of acceleration overshoot. One final refinement was the addition of a G sensing switching unit in the TRU which permitted either standard drogue deployment delay of 1½ seconds (at low speed, low altitude), or delayed drogue deployment appropriate to the negative G force loading imposed by deceleration. The M-B "guillotine" device for cutting the drogue withdrawal line to the seat was also used for the first time in the Mk.IV seat, a feature which has remained an important component of M-B automatic seat systems. Modification was also made to the leg restraint strap system. The idea of incorporating built-in rigid foot rests had been long since discarded on M-B seats (most American seats built in the early 1950s also used the rigid footrest feature, although this was also discarded by US seat manufacturers in the mid 1950s, in favor of the leg restraint strap concept).

The next step in M-B seat development, the production of the Mk.V seat, was substantially influenced by the M-B/US Navy ties referenced in the previous chapter. Largely due to the requirements of the Navy, the basic Mk.IV seat was structurally modified to withstand greater deceleration loads (40 negative G, instead of 25), as was the seat harness system. Featuring the 80 foot per second ejection catapult and most of the features of the Mk.IV seat, the new US Navy specification Mk.V family seat began service in the late 50s and early 60s, and was eventually installed in over 20 different American aircraft types (this includes the later Mk.VII rocket powered version, which was markedly similar to the Mk.V but featured the installation of a rocket unit under the seat-pan). Most of the US Navy Mark.V seats were upgraded to the later, rocket-powered Mk.VII version at a later date. The Mk.VII seat featured a prominent change in the personal parachute container component, which was manufactured in an inverted U-shape of fiberglass (in contrast to the shaped metal parachute fitment shroud and U-shaped fabric parachute pack in use on the Mk.V), and had two compressed springs situated between the seat structure and the container to help fling the container somewhat out and clear of the seat on chute deployment (it remained tethered to the seat, however). There were also minor changes in the thigh portion of the seat pan. Suffice it to say that the addition of a rocket power unit to the Mk.IV and Mk.V seats resulted in the Mk.VI and Mk.VII seats, although that is considerably oversimplifying the process.

In the early 60s, many American aircraft purchased by NATO nations began to be fitted with Martin-Baker Mk.V seats. Norway was the first nation to have the American manufactured ejection seats in its F-86 and F-84 type aircraft replaced by Mk.V units, and Germany and others shortly followed suit; Denmark had much earlier (in 1950) placed an order for a number of UK Meteor fighters fitted with the Mk.I seats, demonstrating the design effectively to the rest of Europe’s allies.

Several other specially designed seats produced by Martin-Baker were their rear-facing ejection seat design (first live-fired in 1960, proving the concept) for UK "V-bombers," and a Mark.V based egress system configured to fire underwater, eject the pilot from his ditched aircraft, inflate his life-vest and bring him to the surface automatically, even if he is unconscious.

As mentioned earlier, the purpose of the rocket-seat development program at Martin-Baker was principally to provide enhanced low-level escape. The original Martin-Baker rocket unit was a twin-tube design with an adjoining nozzle chamber, fitted under the seat and firing downwards. This system was first successfully tested with a "live ejection" in April of 1961. M-B rocket seat systems strive to ensure a near vertical trajectory away from the disabled aircraft. This is allowed owing to the fact that the M-B seat uses a conventional ejection gun and separate rocket propulsion system which are sequentially actuated by the egress system’s automation. This stands in marked contrast to other systems, such as that routinely employed by most US manufactured ejection seats of the 1960s, which combined the ejection catapult and rocket charge in a single gun. The combined gun system functions as a standard explosive charge ejection catapult until the automatic sequencing device allows it to discharge the rocket charge rearwards at a 45 degree downward angle, thereby achieving a slightly less vertical, 45 degree upwards and forwards trajectory.

The combined gun concept is less desirable for low level and "unfavorable aircraft attitude" situations (nose down, low level, low speed), while the separate rocket pack approach allows, in theory, more altitude to be gained in a vertical plane for safe chute deployment and recovery. Martin-Baker was a pioneer in developing this system at a time (1960s) when most other seat manufacturers retained and used the less ideal, although somewhat simpler, combined gun system.

Mentioned earlier, one important modification of the UK's Mk. VII series was specifically designed and fitted to the Lockheed F104G Starfighter (export version for NATO, particularly used by West Germany in extensive numbers). This seat was the M-B Mk. DQ-7 seat. After a series of severe pilot injuries were experienced by aircrew upon emergency ejection using this seat, an investigation showed the cause to be due to the pilot's knees fouling on the forward instrument panel of the Starfighter cockpit. Resulting modification of the seat's main chute containment system, which allowed placing the pilot further aft in the seat, resolved the difficulty. This and subsequent seat modifications led to adoption of the M-B Mk. GQ-7F in Starfighters, with the final modification designated the Mk. GQ-7W. This seat is still in service with the Italian Air Force's Starfighters, as Italy acquired the remainder of former German F104Gs when that nation replaced its Starfighters with newer aircraft. The photograph to the right shows a Luftwaffe F104G egress display at the Munich Museum of Science's Aviation Section, in which a pilot is shown in mid-ejection from a stricken Starfighter.

Another very important seat used extensively by the USN in The F14 Tomcat , and also a derivative of the Mk. VII series seats, was the M-B Mk GRU-7A seat. This seat featured enhanced features, updated system components, and weighed slightly less than the earlier Mk H7AF type seat. This seat has seen extensive service with the US Navy's Tomcat squadrons and has an exemplary survival rate in emergency egress situations--many of which have taken place on or just off of carrier decks.

From the US inspired Mk.VII seat, the next step up for Martin-Baker was development of the Mk.VIII seat; this unit was specifically produced to meet the requirements of the high-performance, experimental TSR-2 aircraft. Although the TSR-2 never flew, the developmental work accomplished by Martin-Baker on the seat formed the basis for a whole new generation of ejection seats that would shortly result in the Mk.IX, Mk.X series, and the latest, high technology Mk.XIV seat.

The entirely redesigned Mk.VIII seat was the first major departure taken from the previous generation of M-B seats and set the style for the current Mk.X and Mk.XIV seats. Among the refinements of the Mk.VIII seat was the elimination of the face-blind ejection actuation feature, a between the legs grab-handle being used exclusively. Also featured was a multi-tube rocket powered unit with twin chamber nozzles and use of the head-rest/drogue containment area for placement of the personal parachute. A special power retraction system was installed which acted to pull the pilot into a favorable ejection position, very much as an earlier unit mounted on the US Navy Mk.VII seats did. Additionally, a remotely actuated rocket firing system was fitted which was a considerable improvement over the previously used rocket actuation device.

The new Mk.IX seat of the mid-to-late 70s benefited from the Mk.VIII development, and with this unit Martin-Baker seats underwent a major reconfiguring. One result, aside from significantly enhanced function, was considerable aesthetic improvement in appearance. Most components of the Mk.IX seat were reworked and advanced features found on the experimental TSR-2 seat were incorporated in the new Mk.IX series seats. These included an entirely new gas actuated seat firing system replacing the previous cable linkages. The face-blind actuator system was discarded in favor a between-the-knees grab handle since studies indicated that such a system was faster to use than a face-blind design (additionally, modern crash helmets provide considerably improved wind-blast protection, making that former function largely redundant). The power retraction system was further improved, and the personal parachute containment area was placed lower in the seat-back, behind a contoured back-rest. Additionally, the seat and back pan assembly was fitted so that it could be quickly removed from the central seat structural members for ease of cockpit maintenance. The Mark IX series seats were installed in Harrier and Jaguar aircraft, for the most part, and their design trends were reflected in the development of the even more improved Mk.X series seats which followed.

Perhaps the most significant improvement found in the M-B Mk.X seat is the incorporation of the pilot’s personal parachute into the head-rest structure containing the drogue system. This is a concept which now appears to be adopted almost universally by egress seat manufacturers; it is now used successfully by the American Stencil Aero Engineering Corporation in their AV-8A (US spec Harrier) Stencil SIIIS seat, as well as by McDonnell-Douglas in the ACESII system. The head-rest container appears to be advantageously sited for optimal deployment of the main (pilot’s) recovery chute and permits simplified, efficient automatic deployment operation. Other improvements found on the Mk.X seats are an extended gas-actuation system, a simplified two-point aircrew harness system, an arm restraint system (in use on the SAAB Gripen and the UK’s Tornado aircraft), and complete design of the drogue gun and barostatic time-release mechanism. The pilot’s personal chute uses a GQ Aeroconical canopy design which permits rapid deployment with reduced susceptibility to severe deceleration forces, and the combined drogue and main chute placement concept allows greater ease in servicing by ground personnel in that the entire combined chute system is removable as a unit. The Mk.X series seats are specified to permit zero/zero operation and safe ejection at speeds up to 630 knots IAS.

Mk.X type seats are used in a variety of aircraft, including the MiG-19 (Pakistan), the Hawk, Tornado, Macchi MB339, CSA 101, Sea Harrier, Northrop F5, SAAB JAS 39, Nanchang A5, K8/L8, the Lavi, and a number of other types in use around the world. Variations belonging to the Mk.X family are the Mk.X-L Lightweight ejection seat and the Mk.X-LF (Northrop F5 upgrade seat); all feature similar systems and specifications / performance capabilities.

The Mk.X-LF is a special retrofit for the Northrop F5 Freedom Fighter which is in use my many nations using that aircraft. The original Northrop seat proved ineffective for low level safe pilot recovery, and therefore selection was made of the Mk.X-L lightweight version of the Mk.X for use in it. (By example, the original Northrop seat provided safe recovery at 1720 feet AGL, at an IAS of 400 knots and a dive angle of 45 degrees. The figure for the M-B seat in identical speed and dive is only 625 feet AGL).

Another more recent Martin-Baker seat is the Mk.XI seat, based upon the successful lightweight seat used on the T-27 Tucano turboprop trainer. The Mk.XI is designed for use in medium performance propeller-driven aircraft and does away with the rocket pack while still providing ground level/60-400 KIAS performance. It features all the advancements of the Mk.XIII (TSR-2) seat, but with substantially less weight.

The Martin-Baker Mk.XII seat is a development of the Mk.X, and very similar to it, but employs pitot-type air and motion sensors to actuate the appropriate safe egress sequencing. Two extendible pitot sensors (one mechanical and the other electrical) on the side of upper seat structure are part of a three component system which determines a variety of parameters to facilitate egress actuation in any of three modes: low level/low speed, low level/high speed, and high level (speed is not factored in in this mode). Furthermore, the seat sensors permit control of parachute deployment in such a manner as to minimise damage which may occur due to severe high-speed ejection forces. The Mk.XII also features a much reduced maintenance requirements which permits a one minute daily inspection for functional readiness, and a three-year servicing schedule.

In 1985 M-B received a contract to produce the Mk.XIV seat for use in the US Navy’s F-14 Tomcat, F/A-18 Hornet, and T-45 Hawk aircraft. This was designated the high-technology NACES, or Naval Aircrew Common Ejection Seat. Utilising the latest in microprocessing technology, the Mk.XIV seat features enhanced operational sensors which permit much greater levels of safe operation in a wide variety of speeds, combat attitudes and altitudes.

Yet another M-B seat is the Mk.XV seat, which was originally developed for use in the Pilatus PC-7 aircraft. An ultralight seat design with a rocket power pack, the very compact Mk.XV seat permits ground-level and 60 KIAS, to 350 KIAS operation in medium performance propeller-driven aircraft. Through canopy ejection is provided as a contingency. Total weight of the seat is only 80 pounds.

The latest and most advanced Martin-Baker ejection seat available at this writing is the lightweight, high-technology Mk.XVI seat. This seat, designed specifically for the latest generation, high-performance lightweight aircraft such as the European Eurofighter and Rafael, features advanced 2nd generation state-of-the-art electronic & microprocessor controlled systems to assure the highest optimal survival margin for aircrew operating the most recently developed aircraft. Offering zero/zero operation and up to 600 KIAS and 50,000 feet operation, the Mk.XVI seat features a weight/mass reduction of 30% over previous seats by combining the twin-catapult gun tubes with the seat structure itself as structural members. Developed as a variant, the Mk.US-XVI-L seat is a special model designed to meet the US JPAT (Joint Primary Aircraft Trainer System) requirement for a lightweight, advanced egress system. Featuring similar specifications to the Mk.XVI, the variant weighs only 125 pounds with full kit and components, and performs safely from zero/zero to 450 KIAS and 40,000 feet altitude. Important also is the seat’s reduced maintenance requirement, which improves on previous late-generation M-B seat standards.

MODERN AMERICAN ADVANCEMENTS: ACES and ACES II

The development of American Air Force ejection seat research continued in the late 60s period with refinements of the Douglas Escapac IC system that led to a new phase of work, conducted under the aegis of the Douglas Aircraft Division of the McDonnell-Douglas Corporation, and based on enhancements to the proven & successful Douglas Escapac system. With Air force use of aircraft originally developed for use by the US Navy (F-4 Phantom II and the A-7, most notably), the merits of the excellent Escapac family of seats became clear and McDonnell-Douglas was charged with principal responsibility for a new, substantially improved system Air Force egress system termed the ACES, or Advanced Concept Ejection Seat.

While work continued on the McDonnell-Douglas ACES program, Stencil Aero Engineering Corporation (Formerly a division of Talley Industries that is now owned by Universal Propulsion Co., Inc.), which had been actively designing and testing aircraft escape systems for military use at both China Lake NOTS and its privately owned Utah rocket sled facility at Hurricane Mesa for years, fielded the other major American seat system recognized as being in the forefront of US seat technology. Stencil innovations included the DART seat stabilisation package that was retrofitted to most older USAF ejection seats, a line of highly engineered and reliable seat initiation and actuation components, and several well conceived and innovative ejection seats that were noted for their structural integrity, light weight, and reliability.

The Stencil SIIIS-3 series of seats was designed to meet the US Navy's requirement for the American AV-8A Harrier and ended up being used in the German Luftwaffe's Alpha Jet aircraft. It was also used at some time in the early F-117 Stealth production aircraft, the Navy F-18 prototype, and the early F-16 FSD aircraft. The Stencil seats departed from prior American designs in incorporating a fiberglass seat pan that covered a soft nylon seat survival package (much like the early USAD MD-1 survival seat kit concept), replacing the entirely "hard" seat kit that was used extensively in the Century Series era aircraft (this return to a previously explored concept was also a feature of the McDonnell-Douglas ACES technology). Stencil was acutely aware of the tendency of ejection seats, both American and foreign, to become excessively ponderous and heavily constructed and favored early development of so-called "lightweight" designs (such as the NAA LW series seats). Stencil seats incorporated a rotating seat kit feature that aided in man-seat separation and used leg restraints and used a series of fail-safed ballistic chute deployment devices. Original SIIIS-3 seats featured a US Navy type face-blind actuation system as well as a between the thigh grab handle actuator, but this was later deleted in favor of the grab handle system. A version of the seat also was produced using standard USAF arm rest grip actuators, which was flown in the early F-117 stealth aircraft. Another Stencil innovation was the RANGER rocket extraction system that was similar in concept to the Stanley YANKEE system (used in the A-1D "Spad") and employed a rocket boosted device that pulled a crew member from a stricken aircraft (this concept was further explored in the aftermath of the NASA Challenger disaster, as a possible egress system usable on the space shuttle).

Other seats designed and produced by Stencil included the SIIIS-3RW "reduced weight" seat, featuring all of the original SIIIS-3 performance, but with a 20% further reduction in overall weight, and the S4S system for use in advanced, high performance jet aircraft. Stencil seats have been used in the US AV-8A & AV-8B Harrier aircraft, several nation's ALPHA jets, the Argentine AF's IA-63, the Japanese Self Defense Air Force's T-4 trainer, and several other types of aircraft, both jet and propeller driven. Although somewhat eclipsed by the USAF's choice of the McDonnell-Douglas ACES system, the Stencil seats remain examples of the finest American egress technology in recent decades.

Meanwhile, the US Air Force adopted the Escapac system, but made basic improvements to the US Navy system to enhance low-level, low speed performance characteristics. This included replacing the Navy's RAPEC I rocket catapult with a higher rated rocket impulse unit (RPI-2174-16) and adding a zero-delay parachute lanyard to increase escape capabilities. The higher energy rocket increased trajectory height and the zero-delay lanyard improved early chute deployment performance to give true zero-zero operation. The high speed capabilities of the Escapac IC system remained unchanged, allowing excellent survival margins at the upper reaches of the operational envelope. Thus modified, the IC-2 seat (used in the USAF A-7D), permitted escape from ground level and zero knots through 600 (or more) knots at altitude. However, despite additional refinements that led to development of the IC-7 seat (used in the early F15A and F-16), it was clear that much work remained to ensure the greatest level of safety for emergency escape by aircrewmen from all corners of the envelope--not just in the specific zero-zero and high performance modes.

A study of emergency Air Force crew ejections over the previous years indicated certain inadequacies of design concepts that were established standards in existing systems. Chief among these problem areas were recovery parachute deployment timing, rocket-burn stability problems, and man-seat separation issues.

The ACES attempted to address all of these areas of concern and it was well noted by US designers that attempts had already been made to correct similar problems in several European seat systems by that date (1970). In an effort to improve system ejection timing sequences, the ACES adopted a refined three stage approach that attempted to reduce the inherent tolerances in the timing sequences through use of more sophisticated electro-explosive actuators (previous actuator components had been largely explosively driven and mechanically timed). Low level/low speed considerations were given higher priorities than had been previously accorded. The matter of rocket burn stability, which had previously been adjusted via aerodynamic devices such as projecting booms, vanes, and parachutes, was corrected to a great degree through use of a gyro-controlled vernier rocket unit (STAPAC). Man seat separation concerns, which in past American seats had been addressed through such devices as rotary actuated straps (Weber and others), inflatable bladders (Escapac), and snubber systems (Stencil DART system--Directional Automatic Realignment of Trajectory), were broached through adoption of a European system in which the deployment of the main recovery chute pulled the occupant from the seat. It was determined that this last approach satisfied concerns over man-seat collisions, additionally. Automatic ejection responses conformed to one of the following three general conditions, to assure the best response consistent with physiological limitations: 1) Low-speed mode (below 275 KEAS, Below 15,000 ft altitude); 2) High-speed mode (Above 275 KEAS, Below 15,000 ft altitude); 3) High-altitude mode (above 15,000 ft altitude).

The ACES seat's physical structure followed lines established by the NAA LW-3B design and the M-B Mk. 15 concept, which optimised lightweight design characteristics, and upper structures were somewhat lessened so as to increase rearward/lateral visibility. The ACES seat fired through actuation of conventional hand-grip control handles, located at the forward bilateral edges of the lower front seat pan (much in the manner of the Weber seats). Catapult values of 18 Gs and

250 gps rate of onset were established as a practical upper limit across the whole range of temperatures and ejected weights. High sink-rate and unfavorable attitude situations were factored into the staging of the catapult main thrust rocket. A pitch control subsystem, linked to the STAPAC components, was configured that offset to a great degree previous thrust centerline sensitivities peculiar to rocket powered systems. Finally, a mortar deployed main recovery chute system was adopted that would most adequately address all points along the anticipated deployment curve (zero/zero to high speed/high altitude); this ejected the 28 foot flat circular main canopy, the inflation of which was also adjusted to ejection parameters by a controlled reefing system.

Additional refinements involved a new configuration for survival kit construction, as the previous all-rigid seat kit design had certain inertial characteristics that were less than desirable in many weapons delivery and ACM profiles. In the ACES system the walls and bottom of the seat's bucket provided the rigid containment needed for the kit contents, allowing a soft (non-rigid) kit configuration to be employed. The non-rigid kit contained two subsection containers, one of which contained items needed quickly (termed the "hit & run" kit) that could be scooped up and carried quickly off to a position of cover. Emergency oxygen capability came from a seat mounted bottle/regulator assembly.

Additional work with the ACES system led to a further improved McDonnell-Douglas ACES II rocket propelled ejection seat system, which has since been installed on most modern American combat aircraft. The Advanced Concept Escape System II (ACES II) followed the years of research and investigation spanning the 1968 through 1975 period that produced the original ACES system just referred to. Chief advances on the ACES II Seat are a gyro-stabilised vernier pitch-control rocket, a sustainer rocket, and a controlled force catapult, which together ensure a much greater range of safe ejection attitudes and situations. The system actively monitors (or senses) environmental conditions such as airspeed, temperature, and altitude, and uses a microprocessor controlled electro-explosive system to properly sequence ejection events so as to safely slow, stabilise and recover the crewman from any point within its performance envelope (which is from zero/zero to over 600 knots IAS). The system is claimed to be so effective that it permits escape from an inverted position 155 feet off the ground and from ground level up to 50,000 feet altitude. As might be imagined, much of the earlier Douglas Escapac RAPEC work helped in laying the groundwork for the ACES I and II systems. The ACES II system utilises an upper seat mounted main parachute configuration, similar to but significantly different from the latest Martin-Baker seats, and is specifically designed to minimise adverse ejection forces such as tumbling and excessive parachute opening shocks. An under-seat non-rigid survival kit is employed in the conventional manner, similarly as was the ACES I counterpart. In 1977 McDonnell-Douglas was awarded a contract to produce the ACES II High Technology Ejection Seat for use in A-10 Thunderbolt, F-15 Eagle and F-16 Fighting Falcon aircraft, following what the company terms a "fly before buy" competition. This culminates the production of more than 6800 ejection seats by the company, according to their statistics. The ACES II system was also installed in the Lockheed F-117 stealth fighter, as well as the Rockwell B-1B and Northrop B-2 stealth bomber. Each application has a slightly customised configuration (for instance, the F16 seat is actuated with a between the legs D-ring, while the B-1B seat has the original bilateral front seat pan control grip actuators first employed by the ACES I seat.

While the ACES II system was until recently arguably the best system American had to provide aircrew escape (the Stencil systems providing much the same capability), the latest American egress technology program is currently underway at this time, being conducted by Boeing in cooperation with the US Air Force. Designated the CREST program (CRew EScape Technology), the purpose of the research is to produce a new generation egress system for the next wave of advanced combat aircraft. Performance criteria for the new open-seat system are reputed to be zero/zero to 70,000 feet and up to Mach 3 speeds, with an "adverse flight configuration" low of 100 feet altitude. The CREST rocket propulsion system will feature 6 to 8 propellant chambers, containing about 60 pounds of propellant, with twin-omni directional thrust nozzles under the control of a microprocessor command unit which has been programmed to recover the pilot from all possible attitudes.

Additionally, the three-part seat program will result in a seat that also provides aircrew protection against high G forces and unusual physical effects while in the aircraft. This is partly required by emerging technologies that include use of what are termed "inherently unstable aerodynamic aircraft" (or aircraft which must be flown with the assistance of computers to maintain aerodynamic stability in flight), and thrust vectoring systems that allow for a far broader range of maneuvering capability with resultant new and unconventional G forces.

It is interesting to note that most recently, a program was also underway in the United States to study the effectiveness of Russian egress systems, the exceptional capabilities of which were most dramatically demonstrated to the whole world by an almost miraculous pilot recovery at the Paris Air Show several years ago, when the Russian pilot's MiG-29 aircraft was literally within a few dozen feet of impacting the ground in a semi-inverted, extremely disadvantageous attitude. Of note are the many advanced features of the Russian seats, and their exceptionally favorable recovery rates, which have been until recently all but ignored by Western egress systems researchers. Much work remains to be done on this but there was at least one cooperative study has been completed investigating the possibility of integrating Russian seats (and/or their technology) into modern high-performance American aircraft--something that would have been inconceivable prior to 1989.

At this time (3/2002) , the decision has been made to continue developing and using US egress technology in the latest US combat aircraft (F-22 *Raptor* and XF-35 *Strike Fighter*) programs.
