ACES II Pre-Planned Product Improvement (P^{3}I) Program Update

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ABSTRACT

Ejection seats are inherently unstable during high and low speed ejections unless positive stabilization devices are incorporated. Today's expanded 103 to 245 pound aircrew size range further challenges seat stability. The USAF ACES II seat is by far the most stable ejection seat in the world under low speed conditions. The ACES II is stabilized at zero to low airspeed with the STAPAC rocket assembly, and is aerodynamically stabilized at high speed by the STAPAC and a 5.0 ft. hemisflo ribbon drogue parachute. The USAF developed the Enhanced Drogue System, as part of the US/Japan Cooperative Modification Project, which improves high-speed seat stability and reduces the aircrew injury risk. Goodrich, the seat OEM, and the USAF analyzed the Enhanced Drogue design under the ACES P3I Program and identified minor modifications that sled testing has shown further reduces the risk of injury without negatively impacting stability or terrain clearance.

Concurrent with the drogue modification, the USAF and Goodrich have developed and sled tested an inertia reel access door retrofit kit for use on ACES II seats. This access door kit allows for inertia reel replacement while the seat is in the aircraft. A USAF decision on a separate inertia reel access door retrofit, versus combining it with the Enhanced Drogue retrofit, is pending. This update describes the process used to investigate drogue optimization and describes drogue reefing time and ratio changes allowing further improvement in MDRC performance for all occupants. In addition, the requirements and installation details of the inertia reel access door retrofit kit will be reviewed.

Expanding the accommodation characteristics for legacy aircraft has challenged the crew escape and cockpit design community. In particular, the small occupant offers challenges in achieving the proper sitting eye height, reaching aircraft controls, and providing safe ejections. As part of the ACES P^{3}I Program, Goodrich was tasked to integrate the accommodation enhancements from the CMP program with the comfort improvement program enhancements resulting in a comfortable accommodation package for today's ACES II. In addition, Goodrich/UPCO has been tasked to incorporate accommodation kit maintenance improvements. Existing accommodation designs, design requirements for the updated accommodations kit, development status, safety impact, and performance data are reviewed.

Limb flail is recognized as a major injury concern during high-speed ejections. The ACES P^{3}I Program includes research and development of passive restraint systems to reduce limb flail injuries. The program is qualifying a retrofittable variant of the F/A-22 passive leg well restraint system for use on the F-15 and F-16 aircraft platforms. In addition, inflatable and net arm restraint technologies are being investigated. Special emphasis is being given to minimizing the aircraft modifications required to install the limb restraint systems into the aircraft. The requirements, design/qualification status, test schedule, and projected fielding timeframe for these systems will be reviewed as part of this update.

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The ACES II seat was developed in the early 1970s, based on seat structure designed in the 1950s. It was designed to accommodate male aircrew in the 5th through 95th percentile size range, while operating within a specified performance envelope. Maintainability provisions in the original (1950s) seat were limited since the design was a relatively simple single piece primary structure with only a single mode of operation. Much of this legacy design was carried forward during development of the more complex ACES II seat. The Modular Seat Program develops a new modular ACES seat structure for retrofit into USAF legacy aircraft which addresses identified limitations of the current structure and incorporates improvements to enhance maintainability, aircrew safety, accommodation, and restraint. The modular structure will allow the seat to be removed in sections, without the use of a crane and without the need to remove the canopy or overhead escape hatches. This revised structure allows continued use of current ACES II subsystems/ballistic components as well as components under development. The structure is weight-optimized, cost effective, and addresses the expanding range of environments experienced by USAF tactical aircraft; including current aircrew population range and changes to field maintainability requirements. Specific program objectives, requirements, preliminary design information, and status are reviewed.

INTRODUCTION

The ACES II ejection seat entered service in 1977. It was designed to a requirement of 5th through 95th percentile male crewmembers. With the increasing number of females in combat aircraft and more emphasis on the larger end of the male flying population, the need to improve the seat's capability was recognized. Several preliminary USAF studies were done to investigate the risk to smaller crewmembers and assess possible seat improvements[1, 2, 3, 4, 5]. As a result, the USAF began a program to meet this need. The Japan Air Self Defense Force (JASDF), whose F-15J/DJ and F-2 aircraft both use Japanese built ACES II seats, had similar improvements in mind. This resulted in a Memorandum Of Understanding between the DoD and the Japan Defense Agency (JDA) and a joint program called the ACES II Cooperative Modification Project (CMP).

The USAF responsibility for the CMP effort was seat stability improvement and system integration. The JASDF's CMP responsibility was crew accommodation improvement and limb restraints. The USAF effort was managed by the Human Systems Program Office at Brooks City-Base, TX. Figure 1 illustrates this division of responsibility.

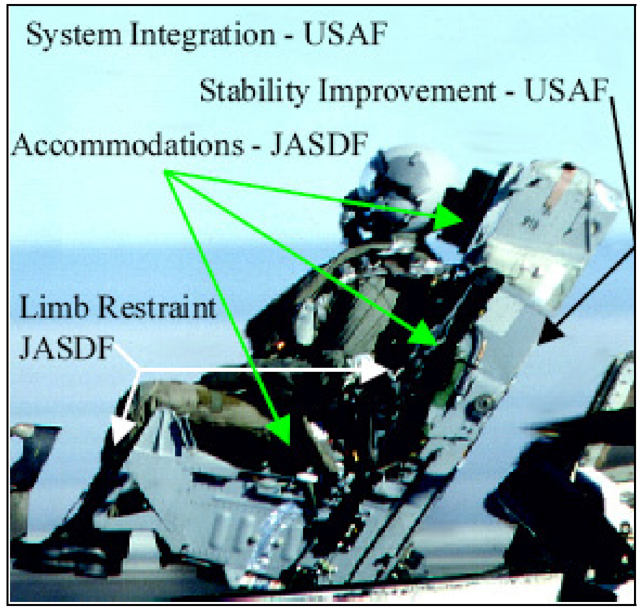


Figure 1 – CMP Project Responsibilities

After the completion of the CMP Program, further enhancements to these subsystems were identified. Goodrich was contracted under the Pre-Planned Product Improvement (P^3I) Program to further investigate these improvements and recommend "go-forward" designs for all of the subsystems including the enhanced drogue, accommodations, and the arm and leg restraint systems. It also evaluates the feasibility of a "modular" seat design which would allow the ACES seats the ability to be removed from the aircraft without the removal of the canopy. These recommendations will also include the plan to modify the existing ACES II seats in service today.

When modifying the ACES II seats with an enhanced drogue system, there is an excellent opportunity to add an inertia reel access door retrofit kit at the same time. Currently, F-15 and older F-16 ACES II ejection seats require the removal of the seat from the aircraft, as well as the removal of the drogue system in order to replace the inertia reel assembly. Under the P^3I Program, Goodrich/UPCO developed a retrofit kit that adds an inertia reel access door to the seat back which would allow the inertia reel assembly to be removed from the seat without removal from the aircraft. This kit is similar in design to the fully qualified access door which was incorporated into later F-16 and all F/A-22 ejection seats (See Figure 2).

In order to install this retrofit kit into the ACES II seat, many key components must be removed, including the drogue system. Ideally, this retrofit could be coordinated with the modifications required to install an enhanced drogue system with little impact to the cost of the enhanced drogue upgrade.

As a follow-on to the P^{3}I Program, the Modular Seat Program develops a new modular ACES seat structure for retrofit into USAF legacy aircraft which addresses identified limitations of the current structure and incorporates improvements to enhance maintainability, aircrew safety, accommodation, and restraint. The modular structure will allow the seat to be removed in sections, without the use of a crane and without the need to remove the canopy or overhead escape hatches. This revised structure allows continued use of current ACES II subsystems/ballistic components as well as components under development. The structure is weight-optimized, cost effective, and addresses the expanding range of environments experienced by USAF tactical aircraft; including current aircrew population range and changes to field maintainability requirements.

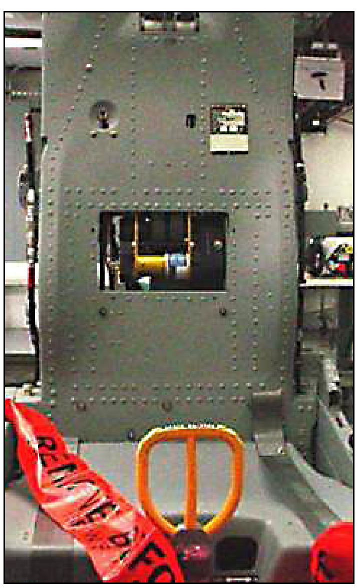


Figure 2: Inertia Reel Access Door

ACCOMMODATIONS BACKGROUND

The ACES II seat was originally designed to accommodate USAF 5th through 95th percentile male aircrew weighing 140-211 pounds (nude weight) ejecting at airspeeds from 0 through 600 KEAS. The USAF aircrew population has changed significantly over the last two decades. Today's population contains both smaller female aircrew and larger male aircrew.

Changes in the aircrew population have required that the aircrew weight range be expanded from 140-211 pounds to 103-245 pounds. Figure 3 provides a visual comparison of typical size differences in today's aircrew and figure 4 graphically illustrates the distribution of male and female aircrew populations. Six cases were originally developed for the Joint Primary Aircrew Training System (JPATS) program. A smaller case size was later added (case 7) and more recently an additional large case was added (case 8). These cases depict the various sizes of aircrew entering service. These cases became the standard for aircrew accommodation in the 1990s.

Figure 3 – Military Aircrew Entering Service

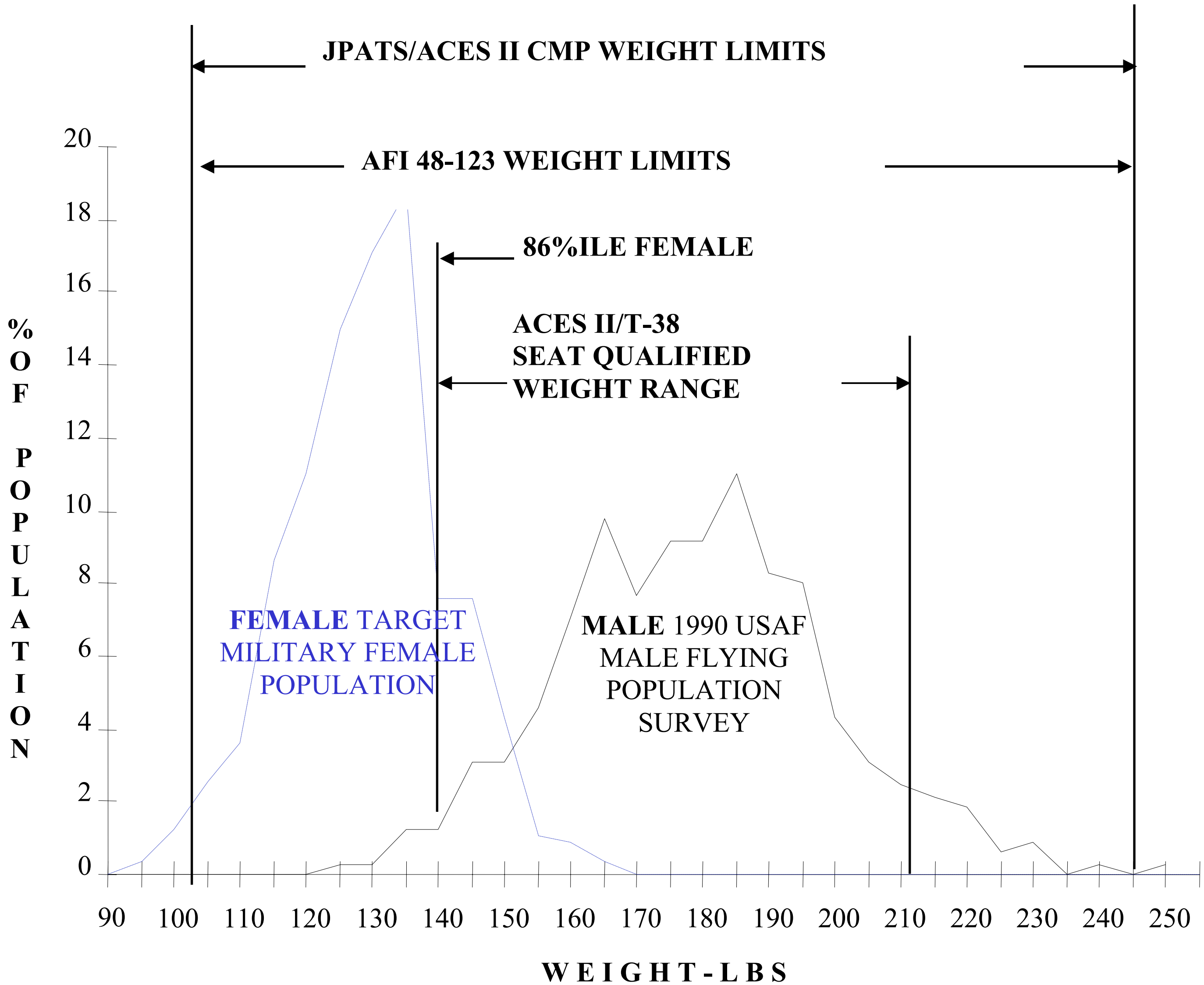


Figure 4 – Distribution of USAF Male and Female Aircrew Weights

Ideally, all existing aircraft would be modified to accommodate the eight JPATS case sizes. However, the dramatic cost of aircraft cockpit and moldline changes necessary for accommodation inhibit implementation. As a compromise, the USAF has established the accommodation of JPATS cases 1 through 7 (103-245 pounds) as the baseline for current in-service USAF ejection seats.

The USAF, in conjunction with the Japan Air Defense Force (JASDF), embarked on the ACES II CMP effort in the late 1990s to develop improvements to the ACES II seat to include an accommodation kit for small aircrew. The accommodations package developed by Japan consists of a revised seat bottom cushion, back cushion, and headrest assembly. When installed, the accommodations package relocates the aircrew approximately 2 inches forward and 2.5 inches upward. Two back pad configurations were developed. One configuration has a straight back pad and the other is tapered. The straight back pad requires an extended headrest to maintain spinal alignment. The tapered configuration allows the head to be positioned the same as before eliminating the need for headrest modifications. The joint development effort and sled test program officially concluded in 2002. The program successfully developed an accommodations package that met the ejection safety criteria as well as the sitting eye height and reach criteria. Dynamic Response Index (DRI) was assessed during CMP sled testing and during drop tower testing conducted by the Air Force Research Lab (AFRL) at Wright-Patterson AFB. The CMP accommodations cushions were found to be acceptable and did not adversely affect spinal accelerations/DRI. A formal USAF Force Development Evaluation (FDE) has recently been conducted which evaluated the operational performance (maintainability, ground, and flight-testing) of the CMP accommodations kit design.

In the mid 1990s, the F/A-22 ACES Program developed and qualified a comfortable contoured bottom cushion for the F/A-22 ejection seat. The F/A-22 cushion dramatically improved comfort over the standard F-15/F-16 style cushion and was well accepted by the using community. Conflicts in the Middle East have resulted in numerous sorties flown by aircraft with ACES II seats. A significant number of the sorties were long duration due to the type and location of the conflict. As a result, the USAF began to look at cushion comfort improvements (based on the F/A-22 style cushions) for other ACES II platforms. The contoured seat bottom cushion and back cushion set dramatically improved aircrew comfort for ACES II seat users.

In 2003, the USAF awarded a contract to Goodrich/UPCO, the seat OEM, to integrate the CMP accommodation technology with the comfort improvement program technology resulting in a comfortable accommodation package for today's ACES II ejection seats. This effort is being performed in conjunction with the ACES P^3I Program effort. As a part of this effort, Goodrich/UPCO was tasked with analyzing head impact attenuation improvements and incorporation of accommodation kit integration/maintainability improvements. These improvements and the system design status are reviewed.

LEG RESTRAINT BACKGROUND

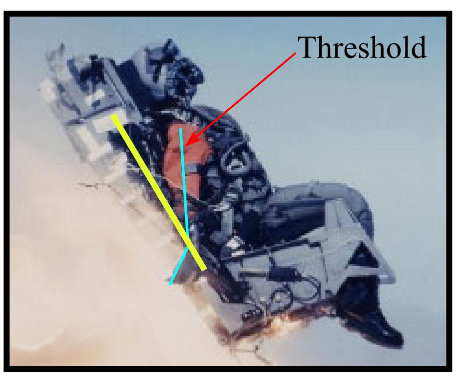
The need for limb restraint during high-speed ejections is well recognized within the escape systems industry. Over the years, seat manufacturers have developed several devices to mitigate the potential for leg flail injuries. The most widely used positive restraint system in recent history consists of aircrew-donned leg garters that retract as the seat leaves the cockpit. More recently, production aircraft with Russian K-36 and ACES ejection seats have incorporated passive, leg well mounted restraint systems. The ACES Program developed and qualified a passive leg well system for the USAF F/A-22 fighter aircraft that is simple and effective. In 2003, Brooks City-Base contracted with Goodrich, the seat OEM, to determine the retrofit feasibility of the passive leg well system for the F-15 and F-16 aircraft. During the course of the ACES II P^3I program, this system was to be demonstrated in both static deployment as well as functional sled testing. Retrofit of the leg restraint system in legacy ACES II aircraft will save the lives of aircrew in the upcoming years and is anticipated to be available for installation into the F-15 and F-16 aircraft in CY 2006-2007 timeframe. Key features of the leg well mounted leg restraint system and performance improvements are reviewed.

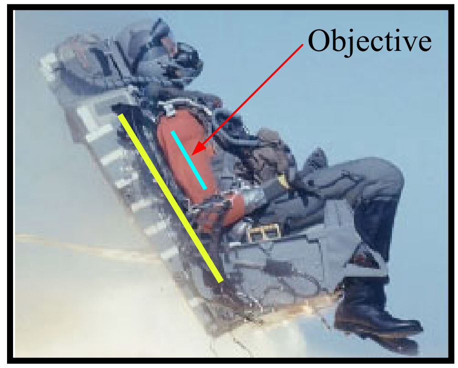
ARM RESTRAINT BACKGROUND

High-speed ejection injury data indicates a strong need for arm restraints to mitigate limb flailing injuries. Developing a restraint concept that is both simple in design and effective has proved challenging for ejection seat engineers. A portion of the CMP effort was to develop arm restraints for the ACES II. At the end of that program, the USAF sought to enhance the performance of the CMP arm restraint system, and was interested in investigating alternative design approaches. As part of the ACES II P^{3}I Program, Goodrich was contracted to propose changes to the CMP system and to develop alternate concepts.

At the beginning of the program a document was written to establish the arm restraint performance requirements. The main requirements for the system are the ability to correctly position and restrain the crewmember's arms during ejection. The system must be compatible with USAF Life Support Equipment (LSE) and be retrofitable with a minimum amount of aircraft modification. Figure 5 defines the key performance requirements. While there is a low probability of serious injury associated with the threshold arm position, the objective position is likely to be less traumatic and significantly better for seat stability.

The CMP arm restraint system uses nets that are deployed as the seat translates up the rails. Analysis of the CMP system concluded that windblast forces and high frictional losses were major contributors to inconsistent high-speed performance. Alternatives for improving performance were investigated, and recent effort has focused on reducing the seat travel required for deploying the system and transferring more force to the system during deployment. In conjunction with CMP restraint refinements, an alternative design under concurrent development utilizes inflatable technology to restrain the arms in lieu of arm nets. Initial test results using these systems are positive with full system tests ongoing. System requirements, design aspects, and performance data are reviewed.





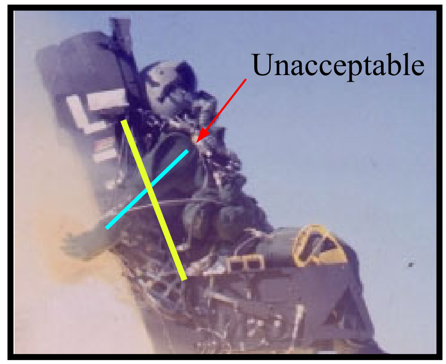


Figure 5 - Performance Requirements

IMPROVED STABILITY BACKGROUND

In more recent years, an increasing emphasis has been placed on evaluating ejection injury risks from accelerations with Multi-axial Dynamic Response Criteria (MDRC)[6]. The MDRC uses a spring-damper model with specific acceleration limits for each body axis to obtain a relative risk value. The maximum MDRC values for the standard ACES II drogue system usually occur at drogue opening. High deceleration compounded by Yaw and Pitch instability is a major factor leading to the peak MDRC value. The human acceleration limits are higher in the front-to-back direction than they are in the other directions and any change from that orientation increases the MDRC value and increases the risk of injury to the aircrew.

A drogue gun, an extraction (pilot) chute and main drogue canopy comprise the standard drogue system. It was apparent that a faster acting drogue chute would stabilize the seat sooner and reduce MDRC values due to instability. A prototype Fast Acting STabilizing (FAST) drogue was tested under the ACES II PLUS program[7, 8, 9] and incorporated into the seat for the F/A-22 aircraft[10, 11, 12]. Figure 6 shows the improved effects of the FAST drogue. The F/A-22 mortar-deployed FAST drogue is mounted on the upper back of the seat (See Figure 7). This method is not compatible with other ACES II cockpits. As part of the ACES II improvement effort, several studies were conducted to devise and demonstrate a method to incorporate the FAST drogue technology into the other existing ACES II cockpits[13, 14, 15]. The current CMP stabilization system resulted from these efforts.

The ACES II improvement plan includes retrofitting A-10, B-1, B-2, F-117, F-15 and F-16 aircraft. Because several thousand seats are involved, cost is a major factor. Therefore, one design common to all aircraft was a goal. With the diversity of cockpits, it quickly became evident that the only modification design that would work for all aircraft cockpits would have to fit completely within the existing seat envelope. Overall system timing needed to be retained to avoid the expense of replacing each electronic sequencer. A tractor rocket (a rocket with nozzles at the top instead of at the bottom) approach was selected as the best fit to the requirements.

At the conclusion of CMP, a few system improvements were identified by the CMP team. These improvements included the optimization of the reefing ratio and timing, and the reduction in collision potential between the enhanced drogue components and the aft occupant(s) in a multi-place ejection event. As part of the P3I Program, Goodrich investigated these improvements and incorporated design changes which further improved the performance and safety of the enhanced stability system. These design changes and test results are discussed.

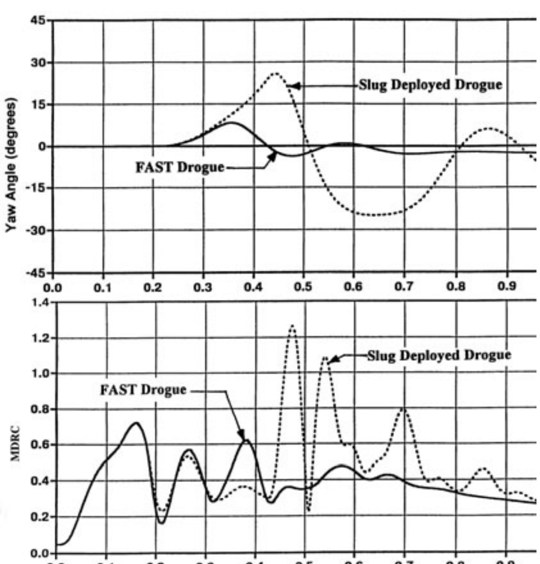


Figure 6 - Effect of the FAST Drogue on Stability and MDRC

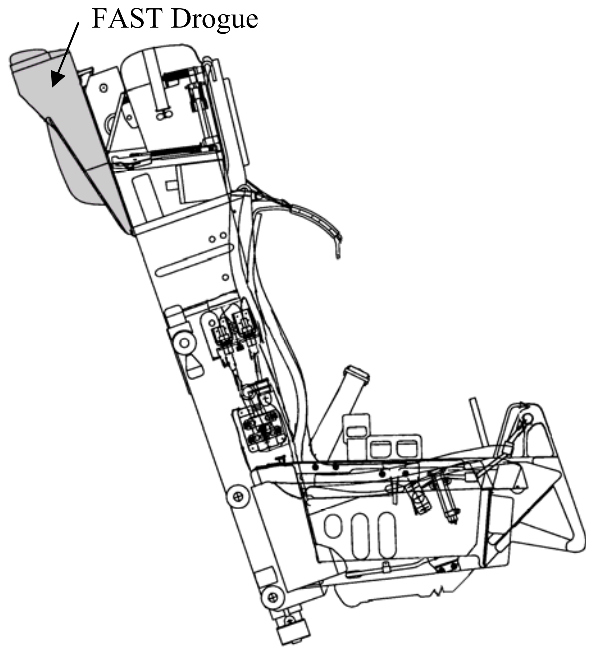


Figure 5 - FAST Drogue.

MODULAR SEAT BACKGROUND

mod·u·lar (mŏj′ə-lər) *adj. Designed with standardized units or dimensions, as for easy assembly and repair or flexible arrangement and use.*[6]

The ACES II seat was developed in the early 1970s. The ACES II structure was based on the ESCAPAC seat structure designed in the 1950s. Maintainability provisions in the 1950s style seats were limited since the design was relatively simple. The 1950s ESCAPAC seats consisted of single piece primary structure with the seat having only a single mode of operation. The ACES II seat evolved into a high performance seat with a significant increase in complexity. However, the basic ACES II structure design still remains similar to the 1950s ESCAPAC design.

Today's military aircraft environment has significantly evolved from the environment 30 years ago. Supportability is a critical element of today's military aircraft. Military budget cuts and staffing reductions are making aircraft supportability more difficult. In addition, squadrons are now expeditiously deployed around the world to resolve world conflicts. Modularization of the ACES seat offers a substantial workload reduction for the maintainer as well as reducing the logistics footprint for deployed squadrons.

ACES II seat modularization allows the ACES II seat to be removed and re-installed in the aircraft without aircraft canopy/hatch removal. Modularization also offers the opportunity to enhance other maintenance characteristics of the seat by providing improved seat component access while the seat is installed in the cockpit and also better access during maintenance in the egress shop.

A modular structure for the ACES II seat was first formally addressed during the ACES Pre-Planned Product Improvement (P^3I) program initiated in 2002 by the USAF Human Systems Program office at Brooks City-Base, Texas. The P^3I program goal was to conduct a feasibility study on modularizing the F-16 ACES seat to allow seat removal/installation without removal of the aircraft canopy. While the task was slated as conceptual only, program specific trade studies generated additional questions and opportunities which led to other potential design and development strategies. The positive aspects of the feasibility study subsequently resulted in this follow-on Modular Seat Program. Specific program objectives, requirements, preliminary design information, and status are reviewed.

Figure 7 - F-16 two-seat configuration.

ACCOMMODATIONS DESIGN

The major task of the seat cushion design is to integrate the CMP and comfort cushion designs together to establish a comfortable accommodation cushion design. The focus of the design is to make installation as simple and easy as possible to enable the crew chief to quickly install/remove the accommodations kit when transitioning between large and small aircrew.

The seat bottom cushion concept is to develop a contoured thick bottom cushion to raise the occupant upward. The maintenance concept is for the crew chief to swap the seat bottom cushion when installing or uninstalling the accommodations kit. The seat bottom cushion has the same interfaces to the seat pan as the current one-inch thick flat cushion. Cutouts are added to the design to facilitate seat bottom cushion installation and access to the back-up parachute deployment handle.

The initial back pad concept is to develop an improved back pad that will integrate with the existing ACES II base back pad that remains on the seat with or without the accommodations kit (this allows the maintainer to install the accommodations kit without re-tacking the emergency oxygen hose). Medium to large aircrew would continue to use the same base pad and back pad/cushion. Small aircrews would use the same base pad, but would require that the existing removable personnel lowering device (PLD) compatible pad be replaced with the thicker accommodations back pad. The thicker accommodations back pad also has a removable lower section to accommodate the PLD.

Figures 8 and 9 depict the difference between the comfortable cushions and the accommodation cushions.

Figure 8 - Comfortable Contoured Cushions

Figure 9 – Comfortable Accommodation Cushions

Figure 10 – ACESII with Headrest Extension Installed

An accommodation headrest extension will be used in conjunction with the straight back pad accommodation cushions and will provide support for the head of those occupants who sit further forward on the seat. (See Figure 10)

The accommodation design team started with the CMP design and incorporated features to simplify the installation/removal and improve the impact attenuation. The original CMP headrest design required modification to the seat structure behind the head pad to install Zeus-type fastener receivers. The accommodation design team objective was to develop a method of attaching the extension pad directly to the current head pad to avoid the need to modify the seat structure.

The design team accomplished this effort by developing a unique attachment concept that allows the accommodation pad to mount directly to the existing headrest pad assembly. The accommodation headrest provisions can be easily retrofitted on the base headrest by removing the existing 6 attachment screws and adding attachment brackets, which will accept the built-in fasteners on the accommodation headrest. This first iteration concept will be evaluated by USAF aircrew/maintenance personnel to determine acceptability.

LEG RESTRAINT DEVELOPMENTS

The qualification effort for the leg restraint system designed to be retrofit into F-15 and F-16 aircraft is ongoing. The principle characteristics of the system are 1) minimal aircraft modification, 2) ease of maintenance and low life cycle cost, and 3) an effective yet passive design.

The difficulty and expense associated with the retrofit installation of previous leg restraint systems has been the single greatest impediment to retrofitting leg restraints into legacy aircraft. Goodrich has developed a system that mounts entirely to the seat and does not require the addition of mounting points on the floor or rails of the aircraft. The only permanent aircraft modification required is bonding the keepers that hold the leg restraint lanyard in the stowed position encircling the leg wells to the interior of the cockpit.

The leg well mounted leg restraint system draws heavily on the lessons learned from both the F/A-22 and the CMP system to maximize reliability, minimize life cycle cost and risk, and simplify the retrofit of the system onto legacy aircraft. The element of this system which allows simple installation into the aircraft is the Leg Restraint Anchor Bracket (LRAB). This bracket, shown assembled in Figure 11, mounts between the rocket catapult and the seat height adjustment actuator. The lanyard pulleys are contained within the bracket and incorporate the shear elements to provide for aircraft/seat separation.

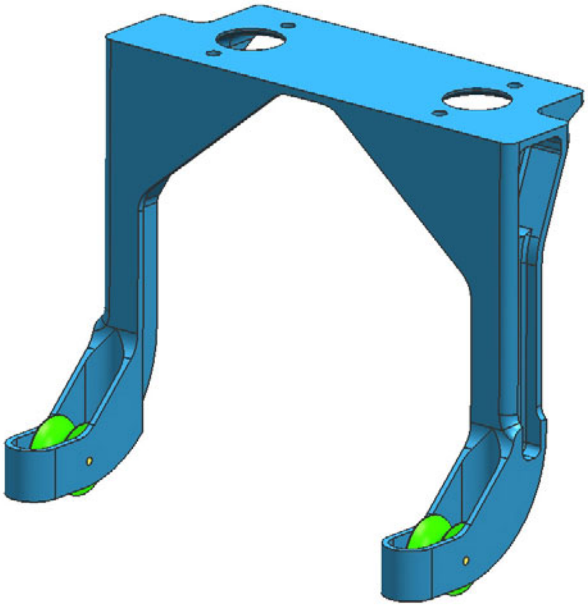


Figure 11 - LRAB Assembly

Figure 12 - F-16 Release Mechanism

Figure 13 - Large Occupant Leg Capture

Other components of the leg restraint system are a hybrid of the F/A-22 system and the leg restraint system developed during CMP. Like the F/A-22 system, the restraint lanyard deploys from the stowed condition by pulling free from the closures on the interior of the leg well as the seat moves up the rails and incorporates a shock cord element to restrain the lower leg of the crew. Like the CMP system, the restraint lanyard routes through a lanyard routing housing after passing through a snubber assembly. In this system, the restraint lanyard is routed through a pulley incorporated in the LRAB, and anchors on the seat structure rather than having the pulley anchored to the aircraft floor.

The release mechanism (See Figure 12) is similar to that mechanism used on the F/A-22 which uses a pin which is retracted at seat/crew separation, freeing the occupant's legs. The design of the release mechanism incorporates features which allow for the installation of safety pins to retain the release clips in the mechanism body during seat maintenance. This eases the alignment of the clips during seat rigging.

Component and subsystem tests have demonstrated effective restraint of the legs and reliable release at seat/crew separation for both 0-0 and high-speed ejection tests using both the large and small representative test manikins. Full system testing is ongoing and qualification is expected to be completed in the first quarter of 2006.

ARM RESTRAINT DEVELOPMENTS

Arm restraint system development has included work on two designs concurrently. The first design is a continuation of the evolution of the CMP arm net restraint system. The second is based on Goodrich's patented SmartBelt™ technology

Refinement of the arm net system has focused on reducing the amount of seat travel required to deploy the restraints, increasing the force transmitted to the restraint by the deployment lanyard and minimizing the aircraft modifications required to retrofit the system onto legacy aircraft.

Optimizing the routing of the net deployment lanyard resulted in a shorter lanyard with less slack while retaining the ability to accommodate both the largest and smallest aircrew (See Figures 14 & 15). The shorter lanyard requires less seat travel to deploy the nets thereby reducing the windblast load on the nets during deployment.

A second change incorporated into the CMP-based arm net system is a quick deployment mechanism (QDM) that utilizes pulleys with a diameter similar to that of the F/A-22 system. These pulleys are significantly larger in diameter than the CMP pulleys. Testing proved that the larger diameter pulleys have a substantially higher efficiency than the smaller CMP pulleys thereby increasing the force available for deployment of the arm restraint system.

Another enhancement made to the CMP system is increasing the shear rivet used to separate the arm restraint system from the aircraft after full deployment. For the proposed system, the rivet size has been enlarged from an AD5 rivet to an AD6 rivet like that used in the F/A-22 system. This increase in the shear force required to separate the deployment mechanism from the aircraft transmits greater force directly to the deployment lanyard which ensures the nets fully deploy (See Figure 16).

Figure 15 – Optimized CMP Lanyard Routing

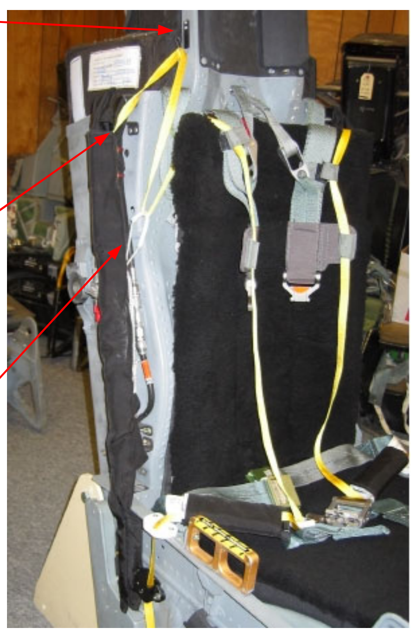


Figure 14 – CMP Lanyard Routing

Figure 16 – Deployed Arm Restraint System

As with the leg restraint design, the most significant advance with the net arm restraint system is the development of the Leg and Arm Restraint Attachment Bracket (LARAB). This bracket eliminates the need for aircraft modifications and dramatically reduces the complexity of the retrofit effort. This design incorporates attachment points for both the leg and arm restraint systems.

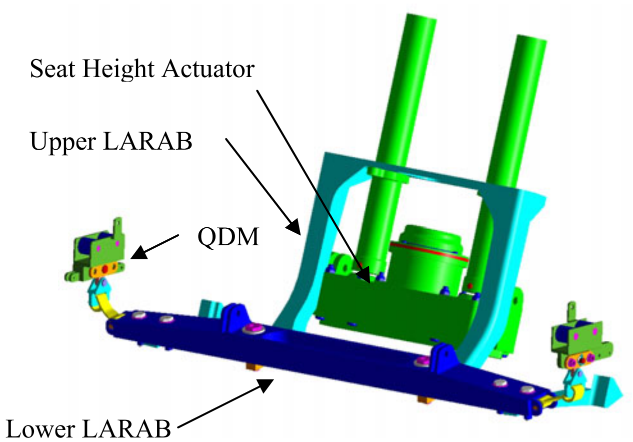


Figure 17 - LARAB Assembly

During the previously conducted Limb Restraint Program, the USAF and Goodrich investigated designs that could use inflatable technology to restrain the occupant's arms in a high-speed ejection. As a result of that program, a concept was selected which utilizes a lanyard to position the arms similar to CMP, but replaces the arm nets with an inflatable device based on Goodrich's patented SmartBelt™ technology (See Figure 18).

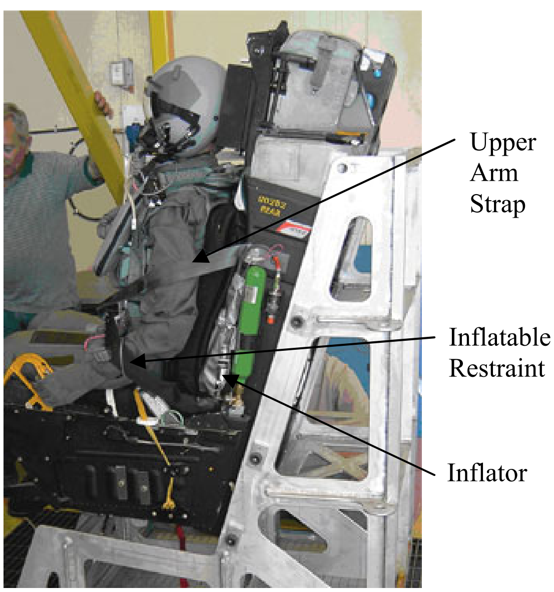


Figure 18 – Inflatable Arm Restraint System

Advantages of an inflatable restraint system include a reduced aerodynamic drag during deployment, the ability to accommodate the entire range of aircrew sizes, and a reduced profile in the stowed condition.

Figure 19 – High Speed Inflatable Arm Restraint Test

The system which releases the occupant from the seat utilizes a release lanyard attached to the inflatable bag which passes through a ring on the deployment lanyard, similar to the CMP arm restraint system. During the CMP sled test effort, this design has proven it can effectively release the occupant, even at high-speed. But while the CMP design included a modification to the seat with an extended release pin from the bell crank to the lap belt fittings, this modified design uses a lap belt fitting like that used on the B-1 and first generation F/A-22. With this approach, no modification is required to either the bell crank or the release pins.

Figure 20 - Inflatable Arm Restraint System

Another of the differences between this arm restraint system and the CMP system is the substitution of a Spectra release lanyard for the Kevlar release lanyard. (See Figure 21) Spectra has a lower friction coefficient and improves the release performance. Additionally, the release lanyard tunnel is now an integral part of the tubular webbing housing inside the stowed inflatable housing.

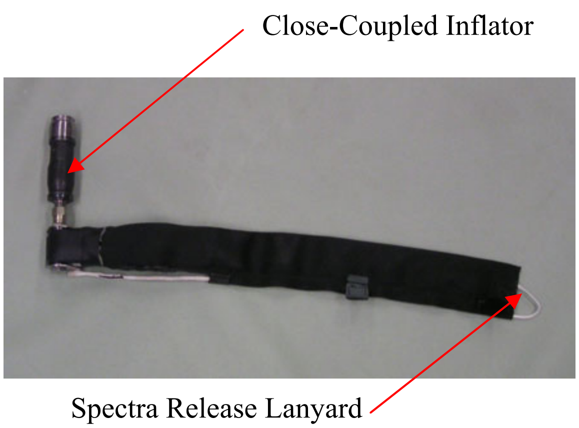


Figure 21 – Inflatable Belt Assembly

Another difference in the design of the inflatable arm restraint system is the seat mounting bracket and the manifold (See Figure 22). The new manifold and mounting bracket requires less volume to install on the seat making the retrofit easier and more beneficial to the aircrew.

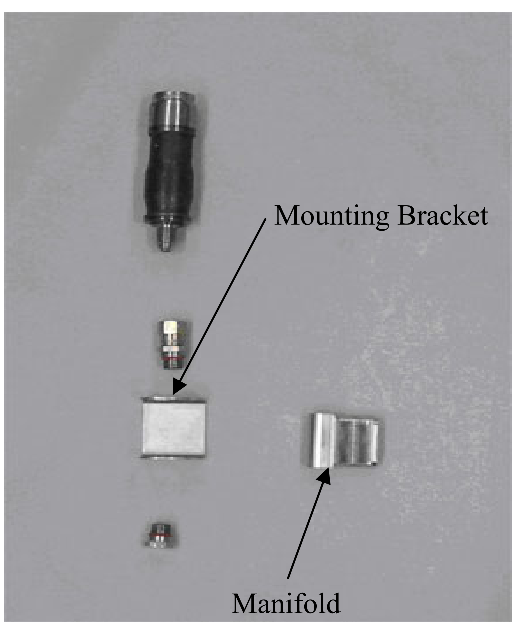


Figure 22 - Current Inflatable System Components

ENHANCED DROGUE SYSTEM DEVELOPMENTS

The analysis tool used for the optimization of the enhanced drogue was the ACES II seat simulation software, Douglas Escape System Simulation (DESS). To verify the validity of the tool for the optimization analysis, Multi-axial Dynamic Response Criteria (MDRC) calculations based on seat accelerations obtained from the simulation were compared to MDRC calculations based on data obtained from the CMP sled tests. The comparison showed the simulation provided reasonably similar results. Test 92E-D1, an F-16 CMP sled test at 513 KEAS using a Lightest Occupant In Service (LOIS) manikin, resulted in an MDRC of approximately 1.12, which was generally expected based on the DESS model output, considering the suspected early failure of the reefing line. This should result in performance similar to the fast drogue, as shown in Figure 6.

As the test data showed, the peak MDRC value occurred just after drogue line stretch, which indicates a reduction of the MDRC peak could be achieved by optimizing the reefing ratio of the enhanced drogue. In order to change the reefing ratio, the reefing cutter delay time also had to be optimized to reduce the effect on terrain clearance, due to the reduced drag area of the drogue.

The reefing configuration optimization analysis focused on the best MDRC performance possible, while considering reefing cutter time delay tolerance. The cutter time delay performance is +/- 20% of the nominal time delay for the operational temperature range. Figures 23 and 24 show the results of the theoretical MDRC analysis for a 1-percentile occupant during F-15 simulated ejections at 600 and 450 KEAS. This analysis included a 0.50 inch lateral offset of the aerodynamic center of pressure and a range of reefing ratios and reefing times. The data between the boxes indicates the current reefing ratio and reefing cutter delay performance (.60 reefing ratio and 0.35sec. nominal, 0.28-0.42 sec. tolerance, cutter time delay). This analysis was also completed for the 1st, 50th and 99.9 percentile occupants for F-15 and F-16 ejections at 600 and 450 KEAS. As the analysis revealed, the best MDRC performance across the range of occupants, velocities, and aircraft, is achieved with a reefing ratio of 0.45 and a reefing cutter time delay in the range of 0.20 sec. to 0.30 sec. To achieve this range of time delays, a cutter with a 0.25 sec. nominal delay was selected. This results in a performance range of approximately 0.20 to 0.30

sec. (+/- 20%). To verify that there is no detriment to changing the reefing configuration to the optimized ratio and timing, a stability and terrain clearance analysis was performed.

The analysis included a comparison of stability and downrange distance in a worst-case scenario of an ejection with an initial 15-degree aircraft yaw. This initial aircraft yaw analysis was also completed for the F-16, at velocities of 275, 450, and 600 KEAS, and 1, 50, and 99.9 percentile occupants. The results showed that the implementation of the optimized enhanced drogue configuration results in slight stability and downrange distance improvements in most cases.

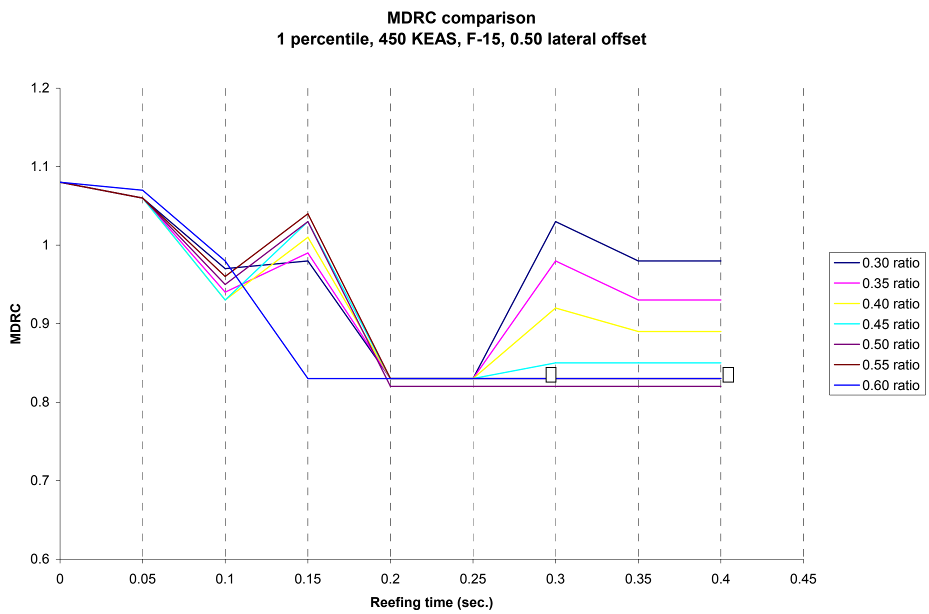


Figure 23 - MDRC vs. Cutter Time for Various Reefing Ratios

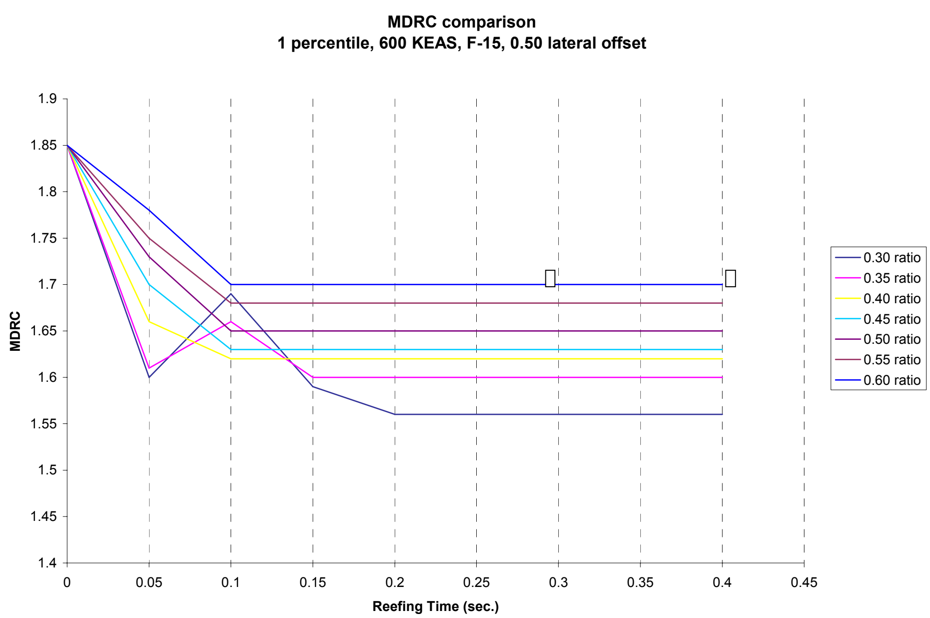


Figure 24 - MDRC vs. Cutter Time for Various Reefing Ratios

The above MDRC analysis resulted in an optimum reefing ratio of 0.45 and a reefing cutter delay of 0.25 sec. nominal (.20 sec. to .30 sec. tolerance). This optimization will theoretically improve the MDRC of the CMP enhanced drogue configuration for a 1 percentile 600 KEAS F-15 ejection from 1.85 to 1.63, and a 50 percentile 600 KEAS F-15 ejection from 1.34 to 1.10. To avoid early failure of the reefing line or increased reefing ratio due to stretch of the nylon line under load, a replacement reefing line needed to be identified. An analysis of the reefing line load was performed, which resulted in the selection of a 2000 lb. Kevlar reefing line and the appropriate cutters. To verify the performance of the optimized configuration, the new reefing configuration has been successfully tested seven times in 2004 and 2005 including five 600+ KEAS seat ejection tests.

At drogue initiation, the tractor rocket pulls the drogue container from the seat, which provides a lines first deployment of the drogue. At line stretch, the container and rocket assembly strip away from the drogue and continue on a trajectory independent of the seat trajectory. This raises the concern of a possibility of a tractor rocket collision in a multi-seat aircraft ejection. This occurs when the disconnected rocket and container assembly of the second ejected seat is propelled in an upward direction toward the occupant of the first ejected seat. Figure 25 shows worst-case ejection clearance scenarios for multi-seat aircraft. This scenario has the heaviest occupant in the first ejection seat, which contributes to a slower deployment sequence, and the lightest weight occupant in the second seat, which experiences a faster deployment sequence. This combination results in the closest trajectory of the first ejected seat and second seat tractor rocket. Figure 26 shows the same combination with the coldest operational CKU-5 catapult temperature allowable (-65 deg F). The cold rocket performance results in a closer trajectory due to the slower performance of the cold soaked CKU-5 catapult.

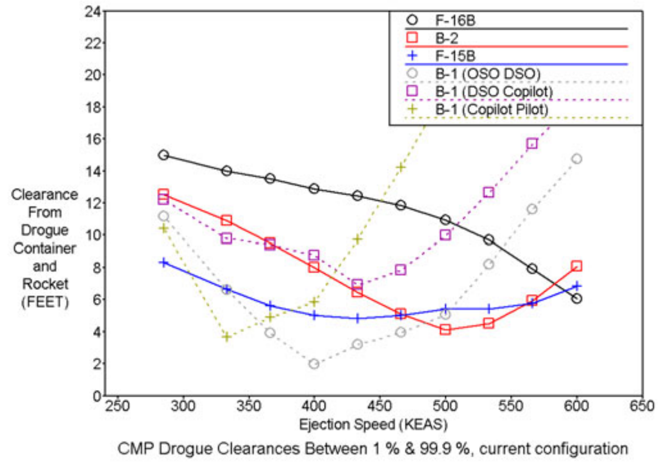


Figure 25 - Tractor Rocket Clearances

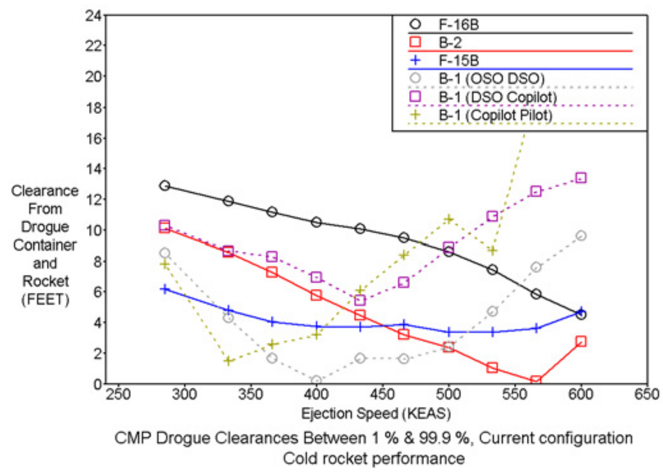


Figure 26 - Tractor Rocket Clearances, with Cold CKU Performance

As Figure 26 above shows, if the worse case occupant combination is encountered while the CKU-5 catapult is temperature soaked at the lowest allowable temperature, a collision risk will exist for the B-1 and B-2 at certain velocities. To mitigate this risk, a second attenuator connecting the rocket/container to the drogue parachute will be utilized to modify the overall trajectory of the rocket/container assembly. This attenuator retards the velocity of the rocket/container thereby lowering its trajectory.

The risk associated with the use of the second attenuator is the possibility of a reduction in seat stability and higher MDRC. This drogue performance reduction is due to the increased inflation time caused by the attenuator load on the drogue bridles during the inflation process. The following second attenuator analysis and figures show the effect of a second attenuator on the performance of the enhanced drogue system. Figure 27 shows the rocket clearance with the use of a second attenuator. As stated before, this rocket collision avoidance method introduces risks to seat performance. Figure 28 shows the theoretical impact of a second attenuator on MDRC for a range of ejection velocities.

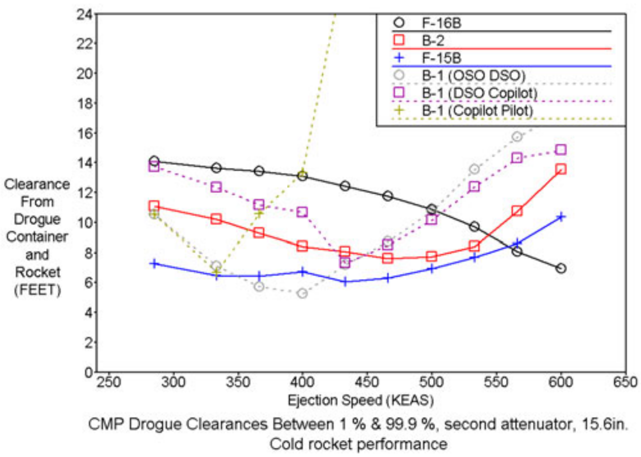


Figure 27 - Tractor Rocket Clearances, with Cold CKU Performance, and 15.6in Attenuator

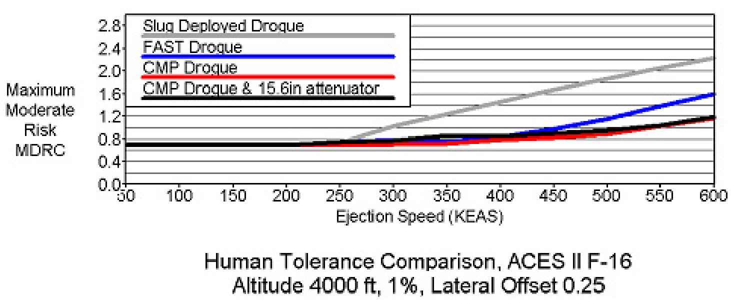


Figure 28 - MDRC Comparison with Standard and Enhanced Drogue with and without 2nd Attenuator

To prove that this second attenuator effectively increased the clearance between the aft occupant and the rocket assembly from the forward occupant, the USAF and Goodrich conducted a dual F-15 seat sled test at HMTF in February 2005. The configuration for this test was to use a 1st percentile occupant in the forward seat and a 99th percentile in the aft seat, the worst combination for rocket assembly clearance. As Figure 29 shows, the 2nd attenuator increased the clearance from 6ft to approximately 12 ft. These results demonstrate that this attenuator can safely increase the clearance between the rocket/drogue container assembly and aft occupants in a multi-place ejection.

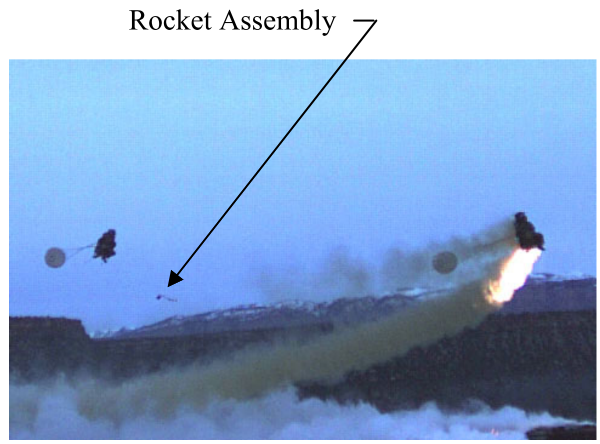


Figure 29 – Dual Seat Ejection Test

MODULAR STRUCTURE DEVELOPMENTS

The ACES II seat OEM (Goodrich) is under contract to develop a modular ACES II seat structure incorporating improvements that enhance maintainability, aircrew safety, accommodation and restraint. This revised structure will also address identified shortcomings in the current structure.

Primary design goals developed under the ACES P^{3}I Phase I program are carried forward to this specific Modular Seat Program. These goals include the base maintenance requirement for removal of the ACES II seat from an aircraft cockpit without the need to remove the aircraft canopy/hatch. In addition to this requirement, the seat must also be removable without the use of any type of overhead lift.

These design goals are driven by factors including (but not limited to) aircraft down time, USAF maintenance practices, pilot and maintainer anthropometric requirements, cost of maintenance, and improved safety. Early trade studies initiated through USAF programs, as well as internal Goodrich programs, have shown that structural modifications based on the specific requirements outlined, offer opportunities to make significant improvements to additional underlying system.

Design philosophy for development of the new modular ACES seat structure addresses the requirements for retention of the strong performance features of legacy ACES structure, the required need for dramatic improvement in seat maintenance characteristics, the incorporation of new technologies and user suggested improvements. The mandate for the structure to be low weight and low cost is also an intrinsic design goal.

Since the original ACES seat structure is based on 1950s technology, there are over 50 years of new technology available for aiding structural redesign. If the previously listed goals are addressed individually, possibilities for improvement are abundant.

The legacy ACES seat performance is proven and carries a worldwide logistics and support base. By design, the modular seat will carry all common subsystems currently operating within the ACES II seat (i.e. CAD/PAD, Recovery Sequencing, etc.). The commonality of these subsystems will ensure continued positive performance characteristics of the modular seat.

Seat maintenance is addressed specifically in the primary design criteria. Meeting overall design goals offers opportunities to implement additional maintenance improvements with limited design impact. Modular structure allowing seat removal from the crewstation for seat maintenance, also allows improved access to the cockpit for on-aircraft maintenance. The division of the seat into simplified modules eases maintainer burden during seat maintenance tasks. Simplified maintenance can significantly reduce overall aircraft-on-ground time.

Early trade studies determined that the modularization of the seat gives the best opportunity to meet the base maintenance requirement for removal of the ACES II seat from an aircraft cockpit without the need to remove the aircraft canopy. Since the seat is also intended to be removable without the use of any type of overhead lift, the weight and physical size envelope of the seat are critical. In order to best achieve the aforementioned maintenance requirements, trade studies have shown that in addition to removal of current modularized components of the ACES II seat (survival kit, parachute container, and catapult), the primary structure itself should be divided into two more maintainable components.

These two primary structure modules are developed based on a division of the current ACES II seat along the forward face of the seat back, through the bucket portion of the seat, to the bottom edge of the seat. This structural division is largely based on individual component weight, access, and maintainability (See Figure 30).

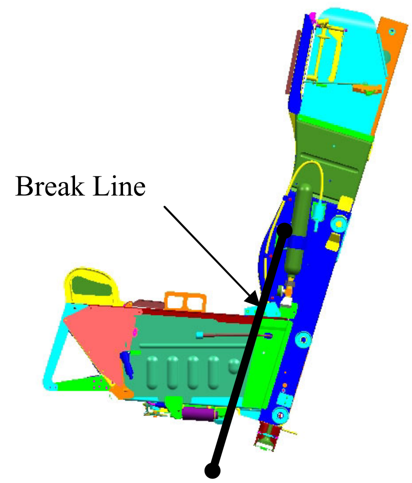


Figure 30 - Division of Current ACES II F-15 Seat

The two primary structure modules will come together on the seat assembly at a modular joint interface. This interface divides not only the seat structure, but also the applicable electrical and ballistic lines necessary for escape system operation (See Figure 31). This 'modular joint' provides maximized access for positive engagement and disengagement of the structure and crossover lines, while maintaining overall system integrity.

Design scenarios include the removal of the survival kit to allow access to the fasteners at the modular joint interface, as well as electrical and ballistic disconnects.

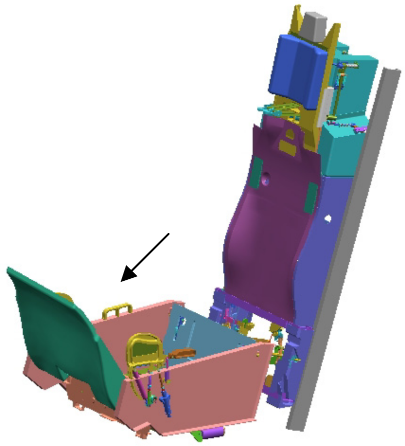


Figure 31 - Separation of Seat at Modular Joint

Since modularity was not considered during original design of the current ACES primary structure, the complexity of any effort to modify the existing structure is significantly increased. A review of the bucket portion of the existing seat, including its common subsystems, illustrates the benefit of going forward with new structure. Figure 32 illustrates the potential of improved design efficiency during redesign of structure.

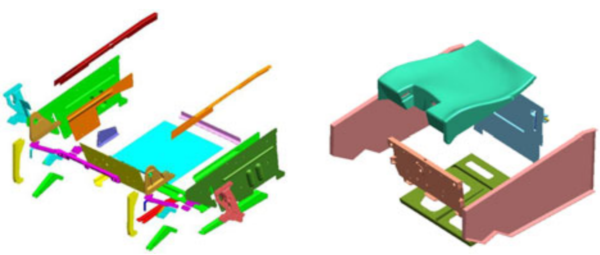


Figure 32 - Current ACES II Structure vs. Updated Modular Structure

Similar design issues exist for the seat back structure as they do for the seat bucket structure. The current design of the back structure, while structurally sound, is not robust enough to fulfill the design criteria for modular seat components (See Figure 33).

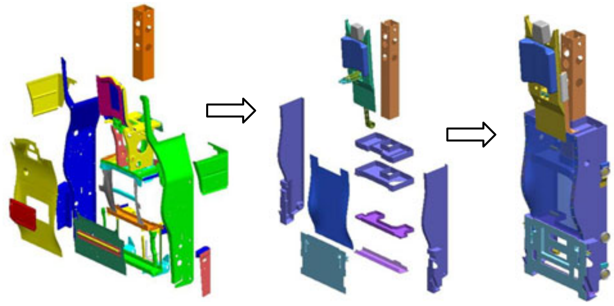


Figure 33 - Seat Back Design Progression – Current ACES II to Modular Structure

While addressing the requirements for seat removal from various crewstations, several issues arise with specific regard to the seat back module. In some aircraft configurations, like the B-2, the canopy is replaced by overhead hatches. This removes any possibility for disengagement of the seat rollers vertically (i.e. at the top of the seat rails). Also, seat components that interface with the aircraft rails are generally located common to the seat back (i.e. start switches and interdictor levers).

The benefits of developing a new structure addressing the above issues, also provides opportunities to make changes to address design limitations and make improvements based on field experience. For example, the need for increased head impact protection can be managed with changes to the headrest structure. Along with a change to the headrest, the structure can be adjusted to accept a more robust, flame resistant parachute container, which incorporates designs for improved pitot deployment. In addition, a large removable access panel can be added to the seat back structure to allow access to all life limited components in the seat back (See Figure 34).

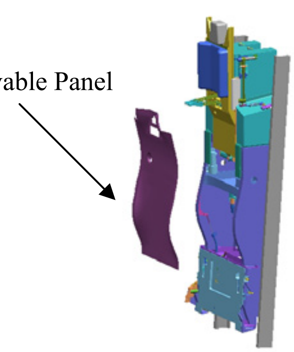


Figure 34 - Seat Back Module with Removable Back Panel

This program is currently in the concept design phase. The fabrication of a mock-up seat and all of the associated demonstration tasks were completed during this phase of the program. The first phase of this program is scheduled to be completed at the end of this calendar year.

Qualification units would be fabricated and delivered for component qualification testing in a follow-on program, to be determined at a later date.

CONCLUSION

The ACES II has been in service for over 25 years and currently there are over 5000 ACES II seats in service. It is by far the most successful ejection seat of all time and, for ejections within the design envelope, has a success rate greater than 99%. The USAF has partnered with Goodrich to not only continue that legacy of success but to improve upon it so that future aircrew will be even better protected.

Current product improvement programs will make the seat more stable during high speed ejections, reduce the potential for injury due to limb flail, and reduce life cycle costs by reducing the time and labor associated with seat maintenance.

The expanded size range of today's aircrew, combined with budget limitations, makes full accommodation of every possible aircrew size very difficult to achieve. The design team has answered the challenge by implementing a program that achieves the accommodation criteria for JPATS cases 1 through 7 to the maximum extent possible without aircraft modifications. The comfortable accommodations portion of the ACES P^{3}I Program has been established to achieve success and is well on along the path to achieve a fieldable design that meets USAF requirements.

The passive leg restraint system developed for retrofit into the F-15 and F-16 is well on its way through qualification. Component and subsystem testing results indicate that the system is effective at restraining the legs during high-speed ejection. The system provides a cost-effective opportunity for F-15 and F-16 units all over the world to increase the flail protection for their aircrew. The 1847-162-01 F-15 leg restraint retrofit kit and the 1847-163-01 F-16 leg restraint retrofit kit are on schedule for completing qualification allowing USAF fielding activities to begin in 2006.

The arm restraint systems being developed under the ACES P3I Program are still in the development stage. But initial test results, including dynamic deployment on a test stand, 0-0 sled tests, and high-speed sled tests, indicate that both deployment and restraint can be achieved for the range of JPATS Case 1-7 crew sizes. Additional, 600 KEAS ACES P3I sled tests are scheduled in 2006. Pending successful results of these tests, the design will be ready to enter a subsequent qualification program.

The original CMP enhanced drogue design deployed the drogue more quickly to improve stability during high-speed ejections. However, with a certain combination of worst-case conditions, there is a significant risk of collision between the tractor rocket of the first ejected seat's enhanced drogue system and the second ejected seat occupant in multi-place aircraft. The addition of a second attenuator mitigates this risk and clearance is improved from 0ft to approximately 5ft for a second attenuator of 15.6in.

The drive behind the design of the enhanced drogue system was to significantly improve stability, which results in a substantial improvement in MDRC and survivability of the ejection sequence. Any additional components added to this system should introduce the least amount of risk of degrading this improvement in stability gained by the enhanced drogue system. Through previously conducted testing, the addition of a second attenuator, in conjunction with the modifications made to the reefing system, have shown that the analysis and simulations are valid in yielding lower MDRC values with reduced risk for multi-place collisions.

In addition to the advantage of injury reduction, a minor modification made to the seat at the same time as the enhanced drogue installation yields a significant benefit in regular maintenance procedures. The inertia reel access door retrofit kit will substantially reduce the time required to remove and replace the inertia reels on the F-15 and F-16 ACES II ejections seats thereby simplifying a regular maintenance procedure. By combining this retrofit with the enhanced drogue modification, it will considerably reduce the aircraft and seat downtime and result in a substantial improvement to the seat performance and maintenance routines. The 1847-112-01 inertia reel access door retrofit kit is nearing the end of the retrofit validation/verification effort and will be ready for USAF fielding activities to begin next year.

The single piece ACES seat structure working within a single mode of operation did not foresee the substantial change in seat operation. Seat maintainability provisions in the original seat are limited due to the simplicity of that original design.

The Modular Seat Program is developing a new modular ACES seat structure which not only addresses those identified limitations of the current structure, but will allow continued use of current ACES II subsystems/ballistic components. In addition, this revised structure incorporates improvements to enhance maintainability, aircrew safety, accommodation, and restraint. Seat maintenance requirements will be dramatically reduced, and new technologies will be evident. This new modular structure that is weight-optimized, cost effective, and retrofittable, will successfully address the expanding range of environments experienced by USAF tactical aircraft.

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BIOGRAPHIES

Mr. Benjamin Sabo is a project engineer for the ACES II Program at Goodrich-UPCO with more than 4 years experience in the escape system industry. Ben is currently the lead engineer on all phases of the ACES II Pre-Planned Product Improvement (P3I) Programs as well as the ACES II ESTAPAC and Modular Seat Programs. Ben graduated from the University of Michigan – Ann Arbor with a BSME in 1998.

Mr. Matthew J. Press is the Human Systems Group Lead Egress Engineer for the Aircrew Protection Division at Brooks City-Base, Texas.

Mr. Press' diverse experience includes employment with Raytheon at Johnston Atoll Chemical Agent Demilitarization Facility; US Filter Blastrac in Oklahoma City, Oklahoma; and the Air Force Research Lab at Wright Patterson Air Force Base, Ohio. Mr. Press graduated from Oklahoma Christian University with a Bachelor of Science in Mechanical Engineering and completed his Master of Science in Astronautical Engineering at the Air Force Institute of Technology with a thesis on multi-satellite control theory.

Mr. John Hampton is the ACES II Program engineering manager at Goodrich-UPCO with more than 19 years in the escape system industry. John has managed the ACES II engineering team through the F-22 ACES II EMD Program, the F-16 ACES II Onboard Oxygen Generating System (OBOGS) Program, the ACES II Structural Upgrade Programs, the ACES II Custodian For Design Programs, the ACES II Limb Restraint Program, the ACES II P3I Programs, the ACES II Digital Recovery Sequencer Program, The ACES II Modularity Program, and ACES II EMSTAPAC Program as well as engineering support for ACES II production. John graduated from the University of Missouri-Rolla with a BSME in 1985 and MSME in 1992.