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

Capt. Demetrius Stewart
Program Manager, ACES II Improvements
Human Systems Program Office
Brooks City-Base, TX 78235

Ben Sabo
Project Engineer, ACES Program
Goodrich AIP
Phoenix, AZ 85027

Will Cromer
Sr. Project Engineer, ACES Program
Goodrich AIP
Phoenix, AZ 85027

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.

Limb flail is recognized as a major injury concern during high-speed ejections. The ACES P3I 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.

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

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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.

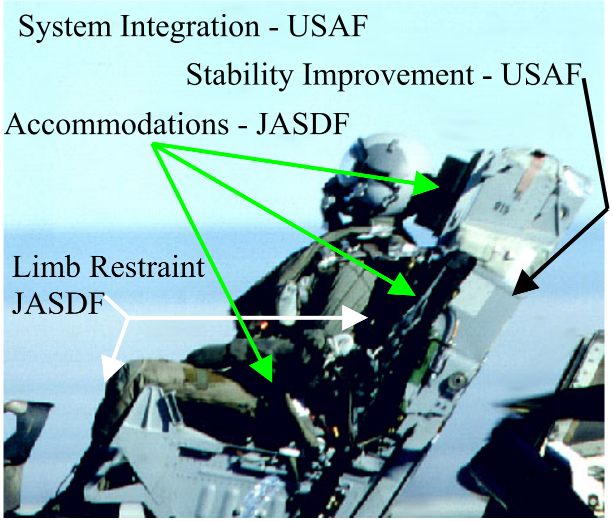


Figure 1. CMP Project Responsibilities

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. 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.

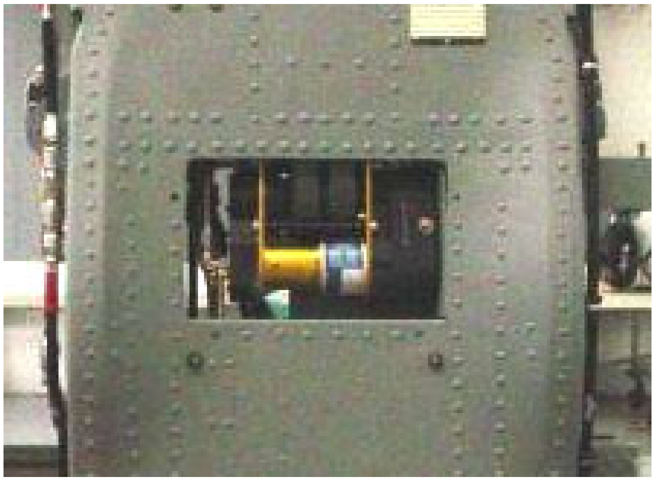


Figure 2: Inertia Reel Access Door

LEG RESTRAINT BACKGROUND

The need for limb restraint during high-speed ejections is well recognized within the escape systems industry. Over the years seat manufactures have developed several devices to mitigate the potential for leg flail injuries. The most prevalent positive restraint system in recent history consists of aircrew-donned leg garters that retract as the seat transitions out of 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, effective, and can be retrofitted into legacy ACES II platforms. In 2003, Brooks City-Base contracted with Goodrich/UPCO, the seat OEM, to determine the retrofit feasibility and to conduct a demonstration of the passive leg well system for the F-15 and F-16 aircraft. This effort was conducted in conjunction with the ACES II P^3I program. 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 2005-2006 timeframe. Key features of the leg well mounted leg restraint system are the installation requirements and safety improvements. Performance assessment are being reviewed.

ARM RESTRAINT BACKGROUND

In-service high-speed ejection injury data indicates a strong need for arm restraints to mitigate limb flailing injuries. Developing a restraint concept that is both user friendly and effective has proved challenging for ejection seat engineers. The USAF recently completed the ACES II Cooperative Modification Program (CMP) with Japan. 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. A contract was awarded to Goodrich to propose changes to the CMP system and to develop alternate concepts.

The CMP arm restraint system uses nets that are deployed as the seat transitions up the rails. Analysis of the CMP system concluded that windblast forces and high friction/mechanical 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 place of the CMP nets. Initial test results with these systems are positive with full system tests ongoing. System requirements, design aspects, and performance data are reviewed.

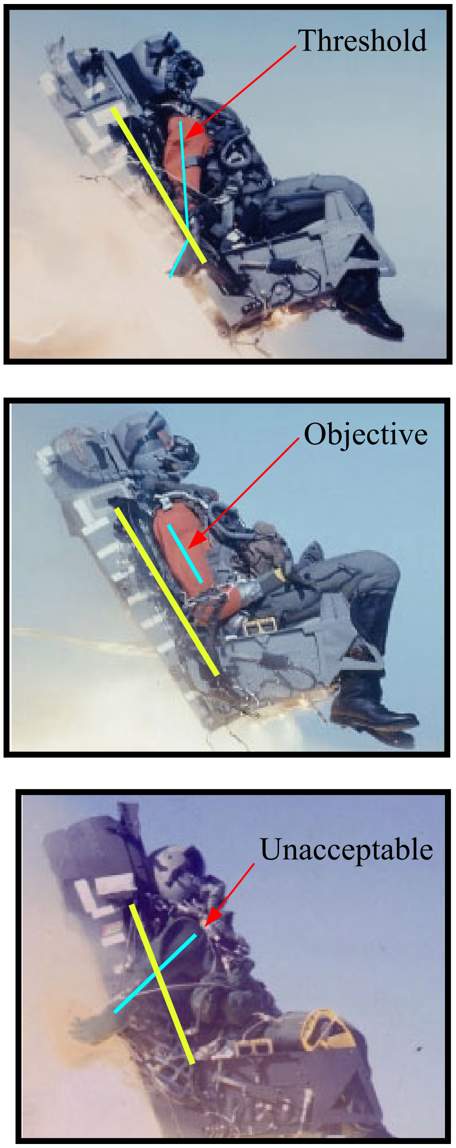


Figure 3. Performance Requirements

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. The figure above 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.

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 4 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 5). 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.

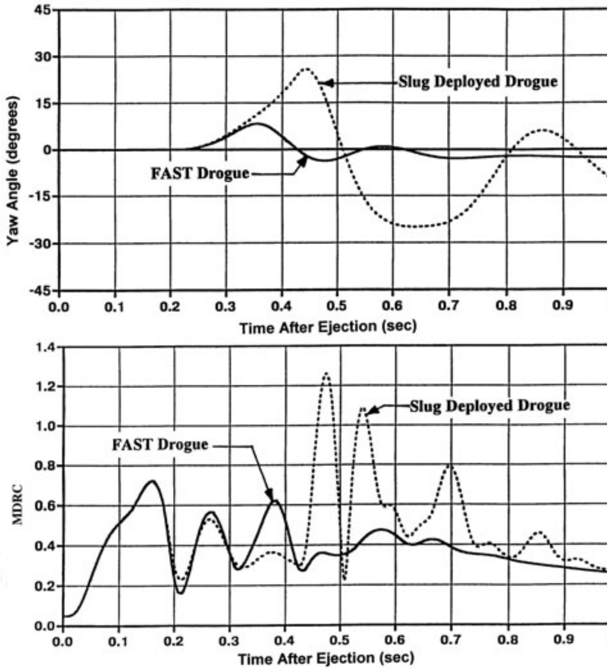


Figure 4. Effect of the FAST drogue on Stability and MDRC.

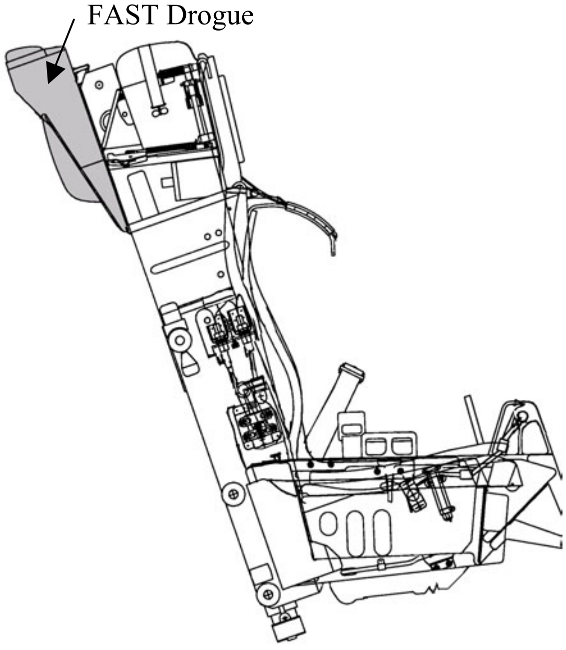


Figure 5. FAST Drogue.

Enhanced Drogue Description

The key components for the enhanced ACES II drogue subsystem are highlighted in Figure 6. The enhanced drogue (and the F/A-22 FAST drogue) is the same shape as the standard 5-foot nominal diameter hemisflo canopy. However, as indicated in Figures 7 and 8, the bulkier parts of the standard nylon chute have been replaced with Kevlar and the suspension lines were made into an integrated bridle, reducing weight and bulk significantly. The drogue is packed separately in an aluminum container, and then installed in the same seat location as the standard drogue.

The tractor rocket is attached to the drogue container by a short cable towline and a shock attenuator, as shown in Figure 9. The tractor rocket is located in a cast steel housing (See Figure 10), which, along with the attenuator, are in the same location as the standard drogue gun and extraction chute (See Figure 11). The rocket initiation squib is the same basic part as the initiator for the drogue gun. It is fired by the same electrical cable from the electronic sequencer.

Because the rocket is located in a separate area in the seat back from the drogue container, it accelerates very rapidly before it starts to pull the drogue container from the seat. The shock attenuator limits the magnitude of the snatch load, and assures a smooth acceleration of the packed container away from the seat. As the drogue container moves, the integrated bridle is deployed from its stowage location in the seat back and container. When the bridle is fully deployed, the resulting tension in the bridle pulls the drogue canopy from the container and inflation of the drogue parachute begins. The overall deployment sequence of the enhanced drogue is captured in the high-speed photographs of Figure 12.

Since the maximum MDRC value occurs during drogue opening shock, reefing was incorporated in the enhanced drogue. This reduces both the maximum opening shock and the maximum MDRC. Figure 13 illustrates the effects of the enhanced drogue on MDRC for a range of seat occupant sizes.

Total time to perform the seat modifications required to retrofit an existing seat to the enhanced drogue configuration is estimated at less than eight hours. Installation of the system in the seat can be accomplished in 30 minutes or less. Air Force sheet metal, survival equipment and egress technicians can accomplish all associated tasks at the local level, without specialized tools or support equipment.

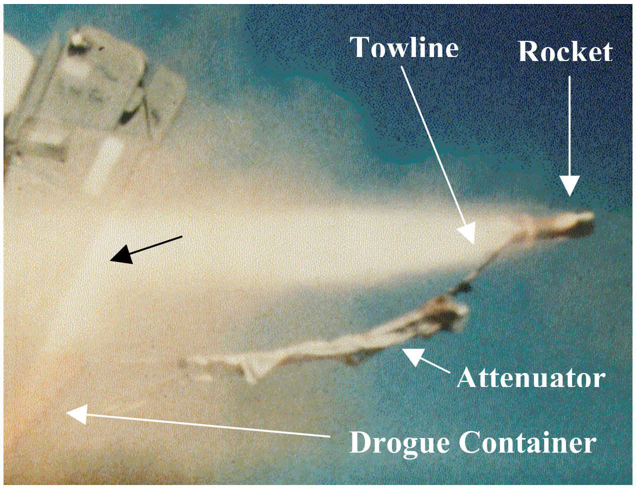
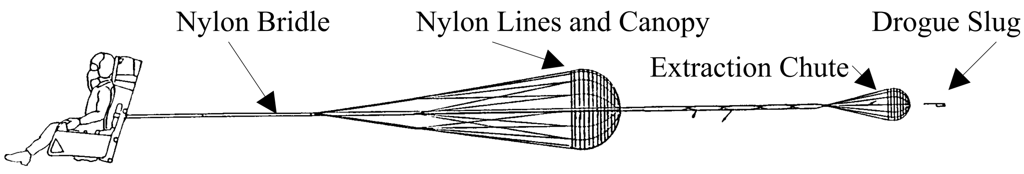
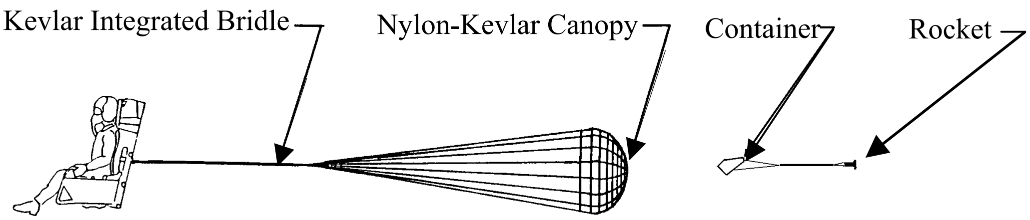


Figure 6. Enhanced Drogue Components.



Standard Drogue Configuration



Enhanced Drogue Configuration

Figure 7. Comparison of Drogues.

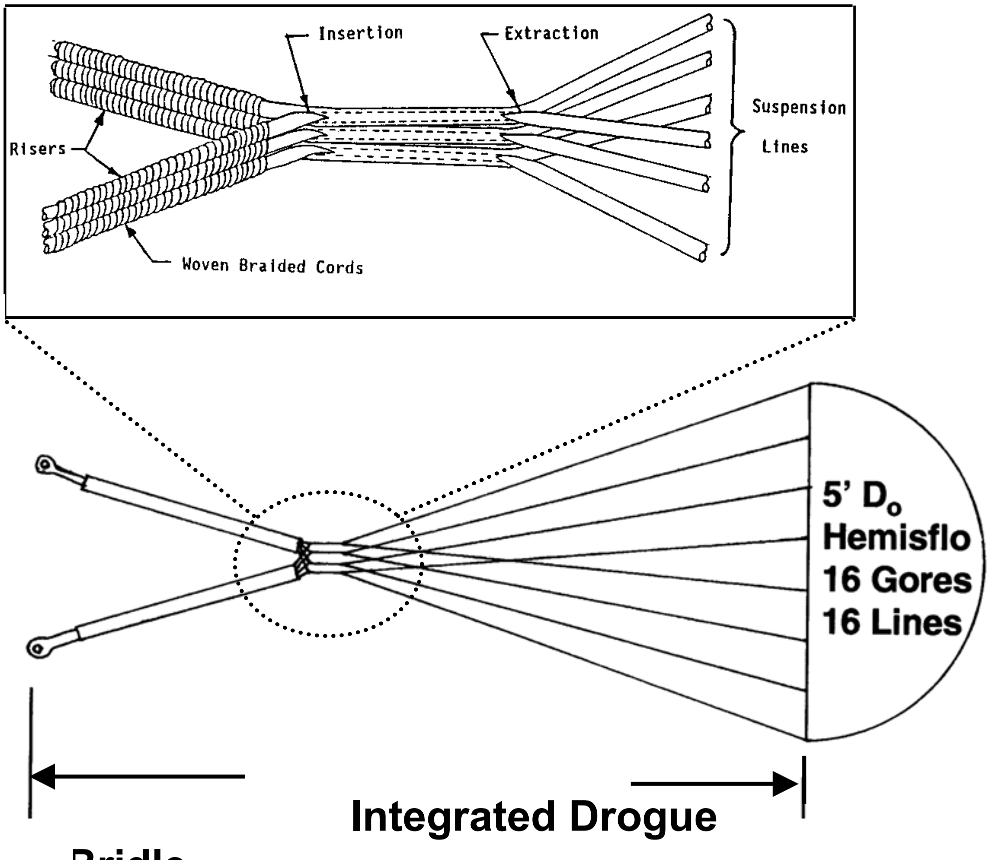


Figure 8. Integrated Drogue Bridle.

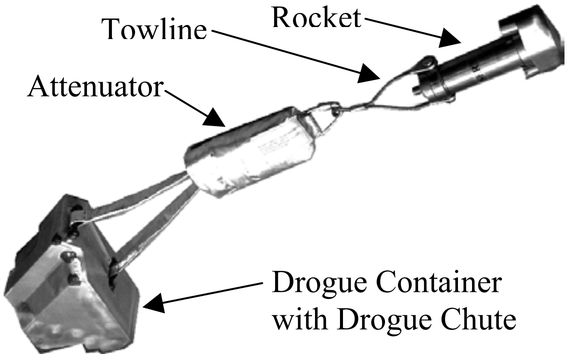


Figure 9. Forces on Drogue Container Are Controlled by the Attenuator.

Figure 11. Enhanced Drogue Installation.

Figure 10. Rocket Installed in Rocket Housing.

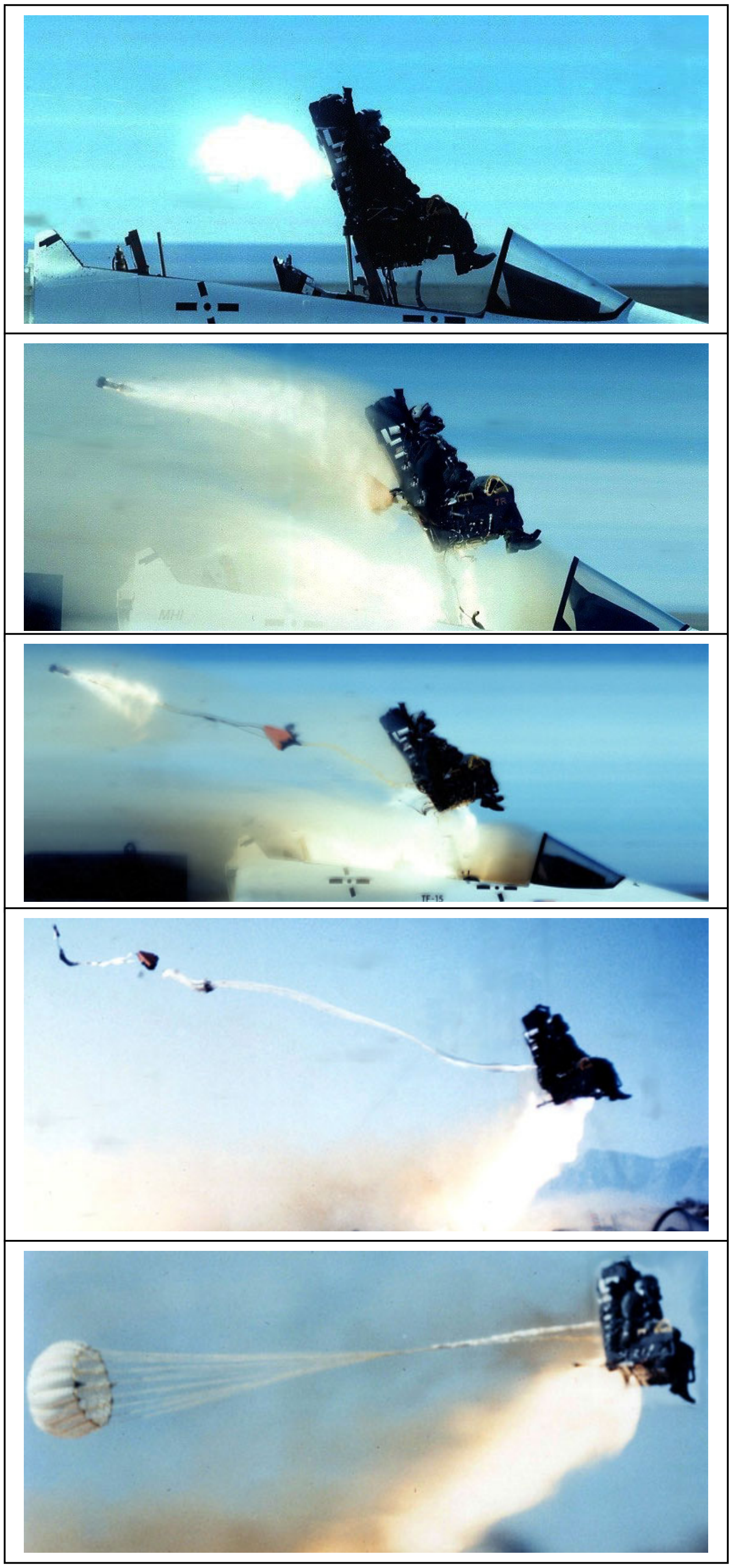


Figure 12. Enhanced Drogue Deployment Sequence.

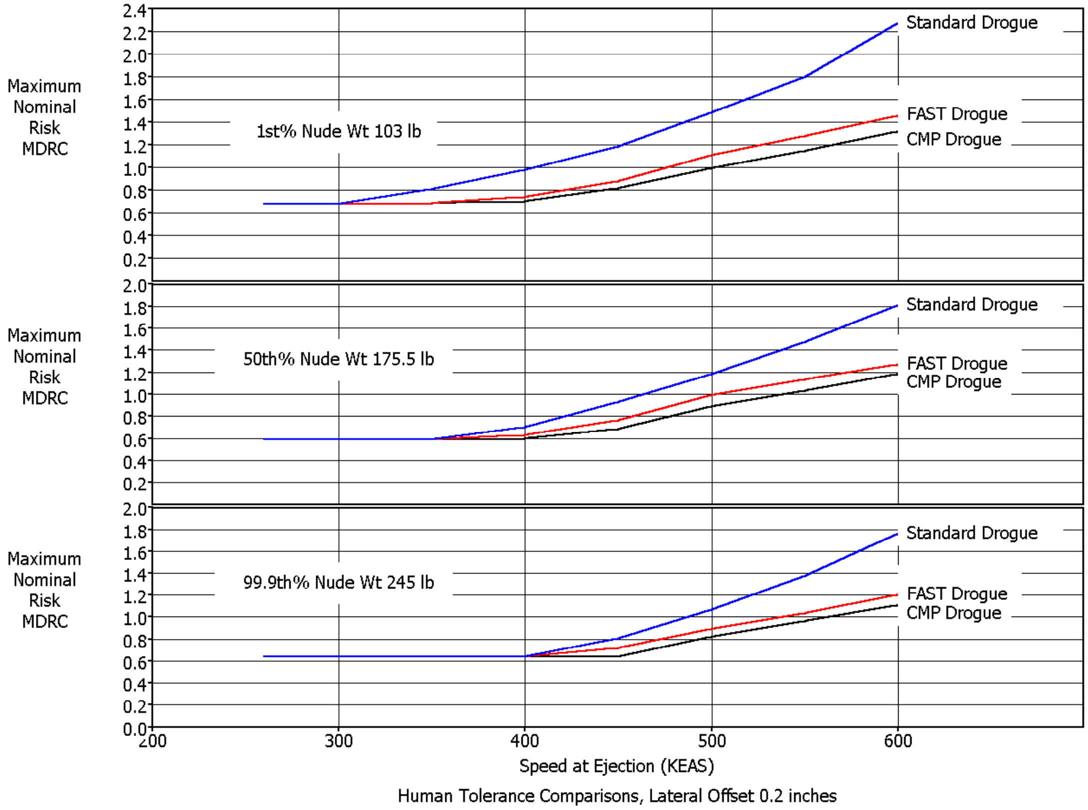


Figure 13. Comparison of theoretical MDRC values for ACES II drogue systems in a generic aircraft

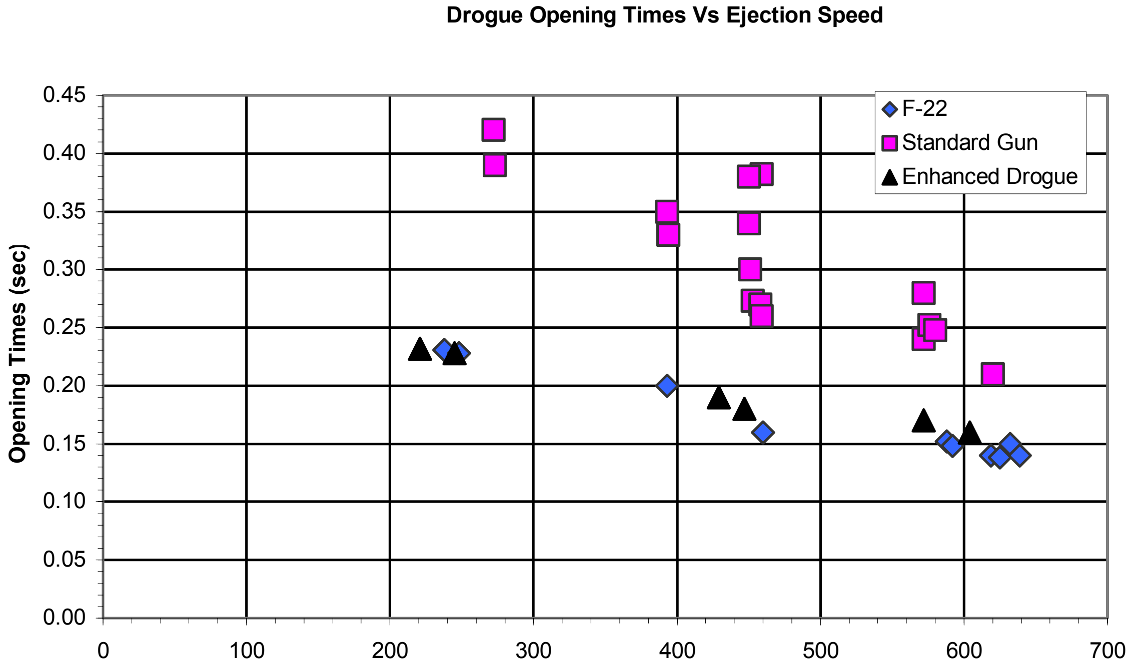


Figure 14. Comparison of ACES II Drogue System Opening Times at different ejection speeds

Inertia Reel Access Door Description

In order to improve maintenance procedures on the ACES II ejection seat, an inertia reel access door was developed to create an easy access point to the inertia reel while the seat was still in the aircraft. The access door was located in the seat back skin directly behind the occupant's lower back. The door is attached to the seat frame by four captive fasteners and the entire system is then covered by the seat cushions.

To increase the rigidity of the sheet metal back skin of the seat, the installation kit includes three mating intercostals which "frame" the door. These intercostals are fabricated to match the seat contour at the appropriate position to allow riveting of the intercostals to both the seat back skin and the seat structure. (See Figure 15)

Another key component of the inertia reel access door retrofit kit (PN 1847-112-01) is the mounting plate and track system which allows the inertia reel to be easily removed from the seat with only two bolts. The plate, which is permanently mounted to the inertia reel assembly, has two "fingers" on the aft side which slide into the mounting track (mounted on the underside of the seat shelf). This allows the inertia reel to be installed by locating the plate into the slots of the mounting track and then affixing the plate with two bolts immediately behind the access door. (See Figure 16) These bolts are easily accessible from the access door and are retained by plate nuts installed on the seat structure.

Total time to perform the seat modifications required to retrofit an existing seat with the inertia reel access door configuration is estimated at less than eight hours. Installation of the inertia reel in the seat can be accomplished in 30 minutes or less. Air Force sheet metal, survival equipment and egress technicians can accomplish all associated tasks at the local level, without specialized tools or support equipment.

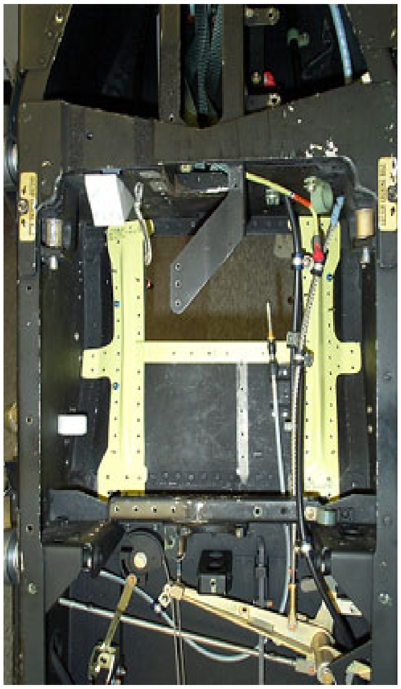


Figure 15. IR Access Door Intercostals

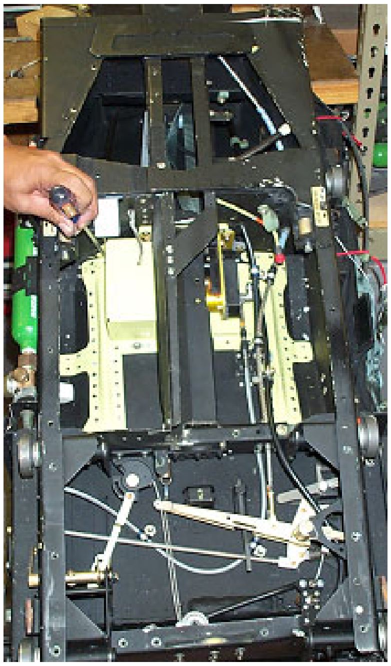


Figure 16. Installed IR Access Door Components

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 passive system.

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 heritage aircraft. Goodrich has attacked that problem through the development of a system that mounts and is anchored to the seat. Thus the only aircraft modification required to install a leg restraint system that is both effective and passive 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 restraint system draws heavily on the lessons learned from both the F/A-22 and the CMP designs to maximize reliability, minimize life cycle cost and risk, and still permit operational units to obtain and retrofit the system to heritage aircraft. The breakthrough element of the leg restraint system design is the Leg Restraint Anchor Bracket (LRAB). This bracket, shown below in Figure 17, mounts between the rocket catapult and the seat height adjustment actuator. The reaction arms mount the lanyard pulleys and incorporate the shear elements to provide for seat/crew separation.

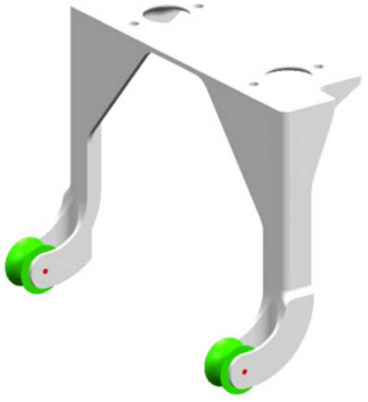


Figure 17. LRAB Assembly

Other components of the leg restraint system are very similar to the system qualified and are currently flying on the F/A-22. 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 design of the release mechanism incorporates features for the installation of safety pins to retain the release clips in the release mechanism during seat maintenance to simplify and speed maintenance.

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 scheduled for the last quarter of 2004 and qualification is expected to be completed in the first quarter of 2005.

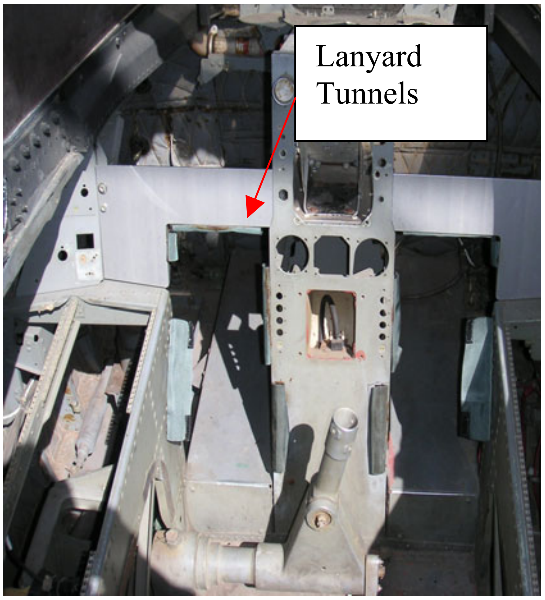


Figure 18. F-15 Sled Lanyard Tunnels

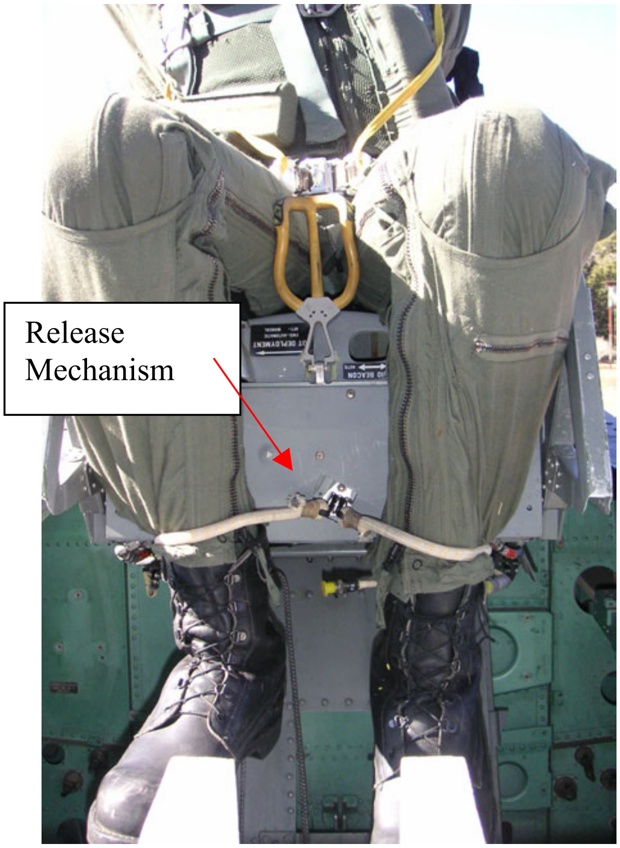


Figure 19. F-16 Release Mechanism

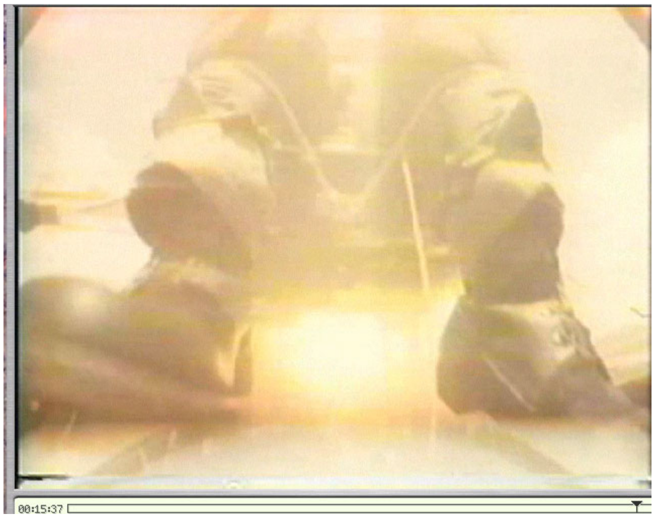


Figure 20. High Speed Test Leg Capture

ARM RESTRAINT DEVELOPMENTS

This phase of the 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^{TM} technology

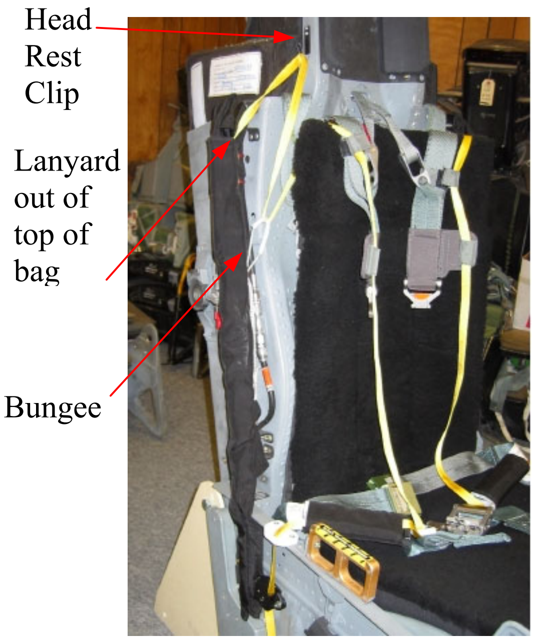
Net Arm Restraint System

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.

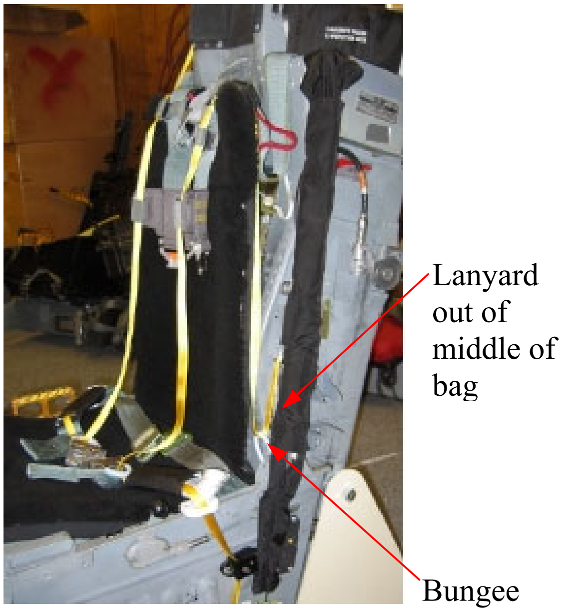
Modifying the routing of the net deployment lanyard resulted in a shorter lanyard with less slack while retaining the required accommodation for the extremes in aircrew sizes. The shorter lanyard requires less seat travel to deploy the nets and reduces the windblast load on the nets during deployment.

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 and thus increase the force available for deployment for a given level of tension in the attachment anchors.

Another change to the CMP system is to the shear rivet incorporated for the release mechanism. For the current system, the rivet size has been increased from an AD5 rivet to an AD6 rivet like that used in the F/A-22 system. This increase in the required shear force in the anchor element transmits greater force directly to the deployment lanyard and ensures that the nets do not release prior to full deployment.



Original CMP Routing



Proposed CMP Routing

Figure 21. Lanyard Routing Comparison

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). Eliminating the need for aircraft attachment brackets dramatically reduces the complexity of the retrofit effort. This design incorporates attachment points for both the leg restraint system and the arm restraint system.

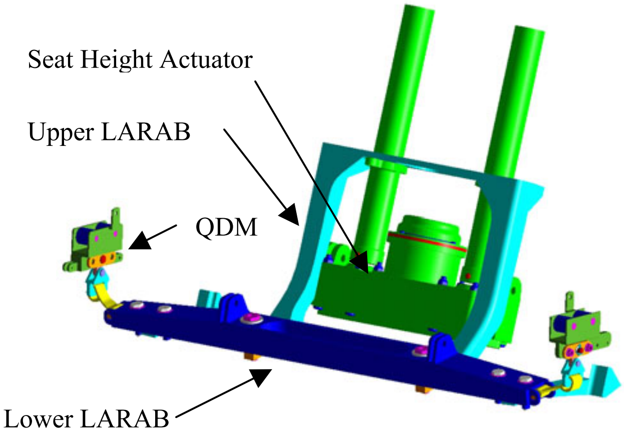


Figure 22. LARAB Assembly

Inflatable Arm Restraint System

During the trade study conducted previously the team investigated designs that would use inflatable technology for arm restraint. The concept selected uses a lanyard to position the arms similar to CMP, but replaces the arm nets with an inflatable device based on Goodrich's patented SmartBelt^{TM} technology.

Advantages of the inflatable restraint system include a smaller aerodynamic area with a potentially improved deployment under high-speed conditions, inherent accommodation for a range of aircrew sizes, and a reduced profile in the stowed condition

The release mechanism that was selected incorporates a ring on the deployment lanyard and a release lanyard to the inflatable, similar to CMP. This concept has demonstrated satisfactory release during the CMP effort. 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, the current design uses a lap belt fitting like that used on the B-1 and first generation F/A-22. With this approach, no modification to the bell crank and release pins is required.

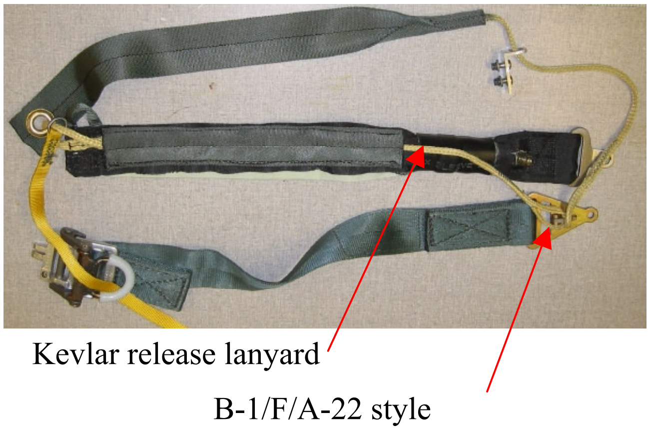


Figure 23. Inflatable Arm Restraint System

As the inflatable arm restraint system design has matured, modifications to the design have evolved to improve performance and simplify installation on the seat.

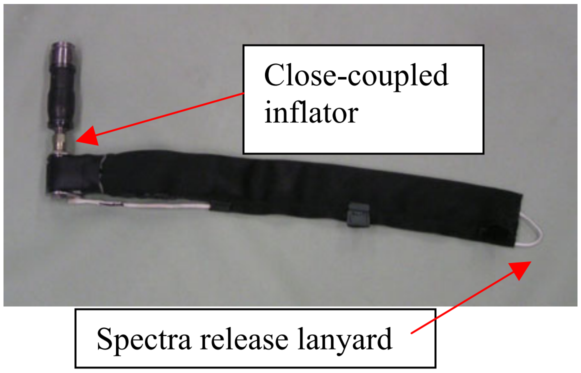


Figure 24. Current Inflatable Arm Restraint

One of the changes is substitution of a Spectra release lanyard for the Kevlar release lanyard. The Spectra has a lower friction coefficient and improves release. Another change is that the release lanyard tunnel is now an integral part of the tubular webbing housing the stowed inflatable structure.

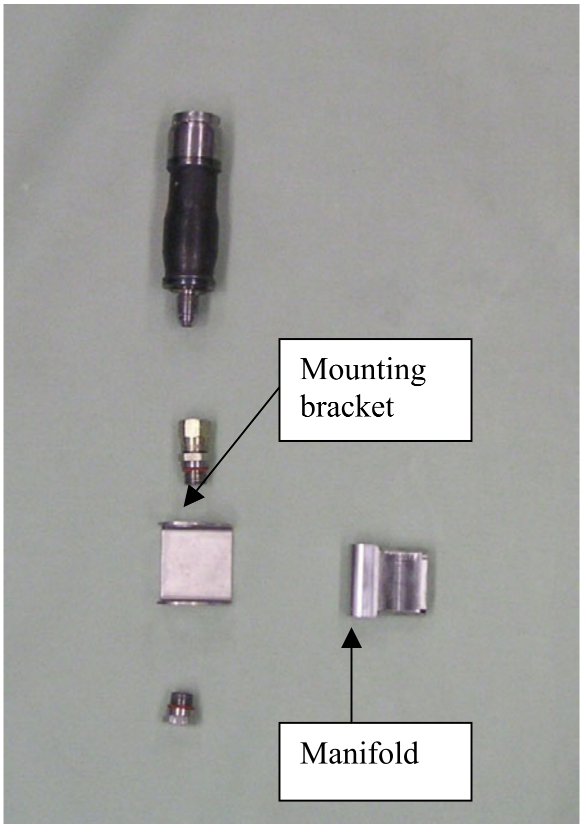


Figure 25. Current Inflatable System Components

A third change to the design of the inflatable arm restraint system is the refinement of the seat mounting bracket and the manifold. The new manifold and mounting bracket reduce the size of the package and facilitate integration of the inflatable arm restraint system into the seat.

Arm Restraint System Testing

Development funds have hampered sled testing of the complete arm restraint system. To date, tests have been conducted on the test stand to simulate deployment, and with the arm restraint systems pre-positioned on sled tests to evaluate restraint.

The test stand testing, reported previously, confirmed the improvement in robustness of the deployment associated with the increase in rivet shear strength associated with the change from the AD-5 to the AD-6 rivet.

The sled tests conducted to date have all been with the arm restraint systems pre-positioned.

Figure 26. Predeployed Arm Net

For the net system, the arm restraint system was configured normally, the manikin positioned in the seat, and the arm restraint net deployed manually. The seat and manikin were then installed in the sled and the sled conducted. Although this did not demonstrate deployment under sled test conditions, it did allow evaluation of the restraint under test conditions provided the deployment occurs properly.

For the inflatable arm restraint system the arm restraint system was manually deployed as above, but during conduct of the sled test the inflators were initiated after an appropriate time delay to simulate the timing that would occur in the installed system.

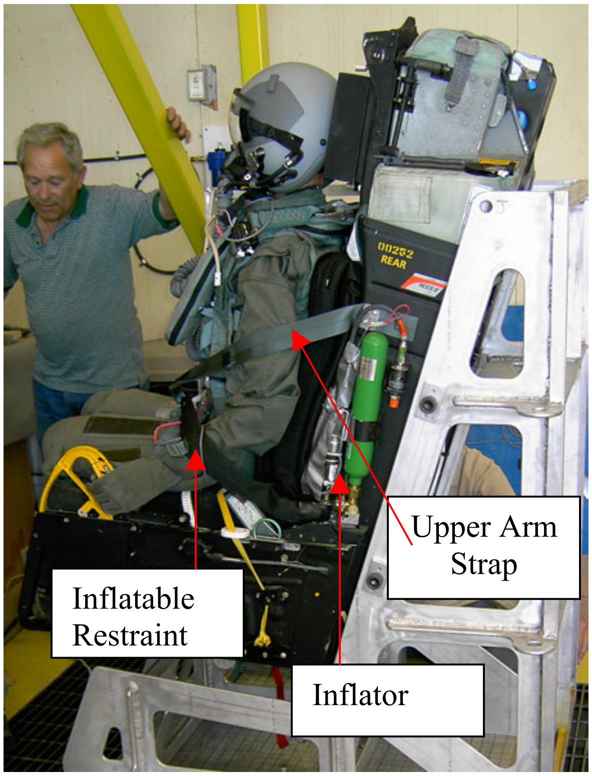


Figure 27. Pre-positioned Inflatable Arm Restraint

Figure 28. High Speed Inflatable Arm Restraint Test

With both the net system and the inflatable restraint system results demonstrate that with the arm restraint in the proper position the arm restraint will prevent arm flail even at test velocities of 600 KEAS. In addition, in all cases the release mechanism allowed clean seat/crew separation.

ENHANCED DROGUE SYSTEM DEVELOPMENTS

Reefing Optimization

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 13.

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 29 and 30 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 1, 50 and 99.9 percentile occupant 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. As the results show, the implementation of the optimized enhanced drogue configuration, results in slight stability and downrange distance improvements in most cases. Figures 31 and 32 show seat yaw, downrange distance, and pitch for the standard and optimized enhanced drogue configuration.

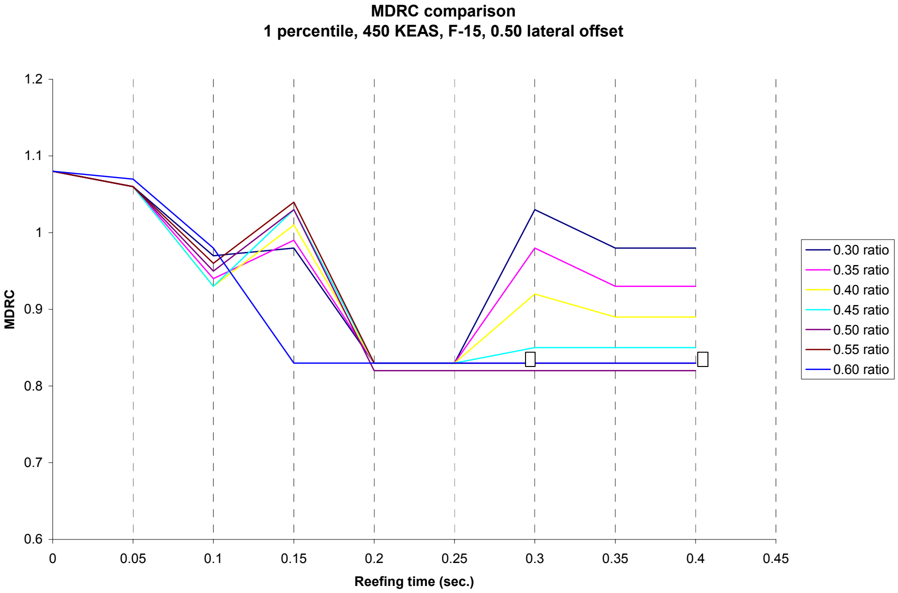


Figure 29. MDRC vs. cutter time for various reefing ratios

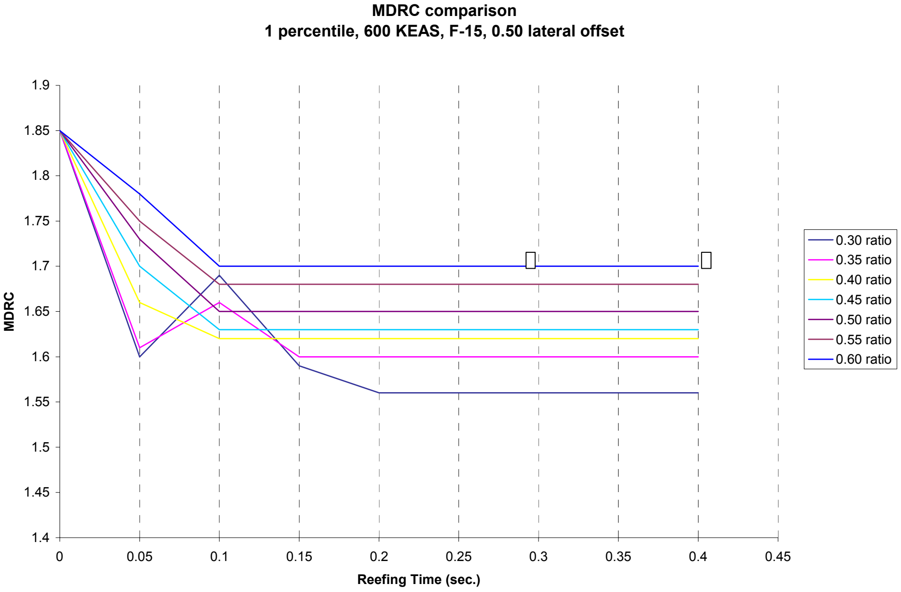
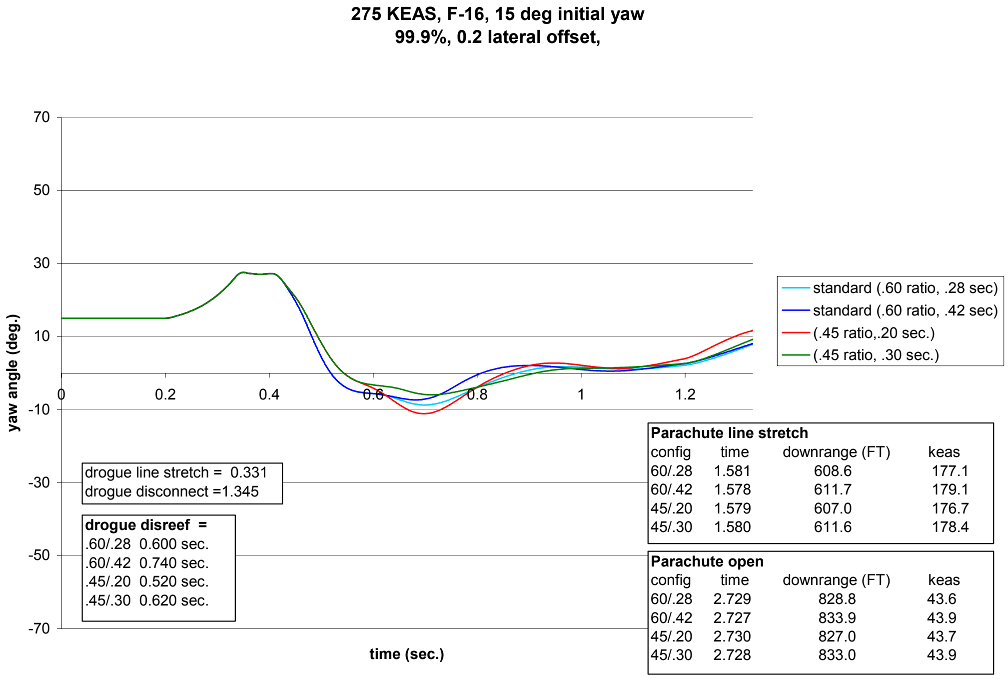


Figure 30. MDRC vs. cutter time for various reefing ratios



drogue line stretch = 0.331
drogue disconnect =1.345

drogue disreef =

.60/.28	0.600 sec.
.60/.42	0.740 sec.
.45/.20	0.520 sec.
.45/.30	0.620 sec.

Parachute line stretch

config	time	downrange (FT)	keas
60/.28	1.581	608.6	177.1
60/.42	1.578	611.7	179.1
45/.20	1.579	607.0	176.7
45/.30	1.580	611.6	178.4

Parachute open

config	time	downrange (FT)	keas
60/.28	2.729	828.8	43.6
60/.42	2.727	833.9	43.9
45/.20	2.730	827.0	43.7
45/.30	2.728	833.0	43.9

Figure 31. Yaw angle vs. time with an initial yaw of 15°

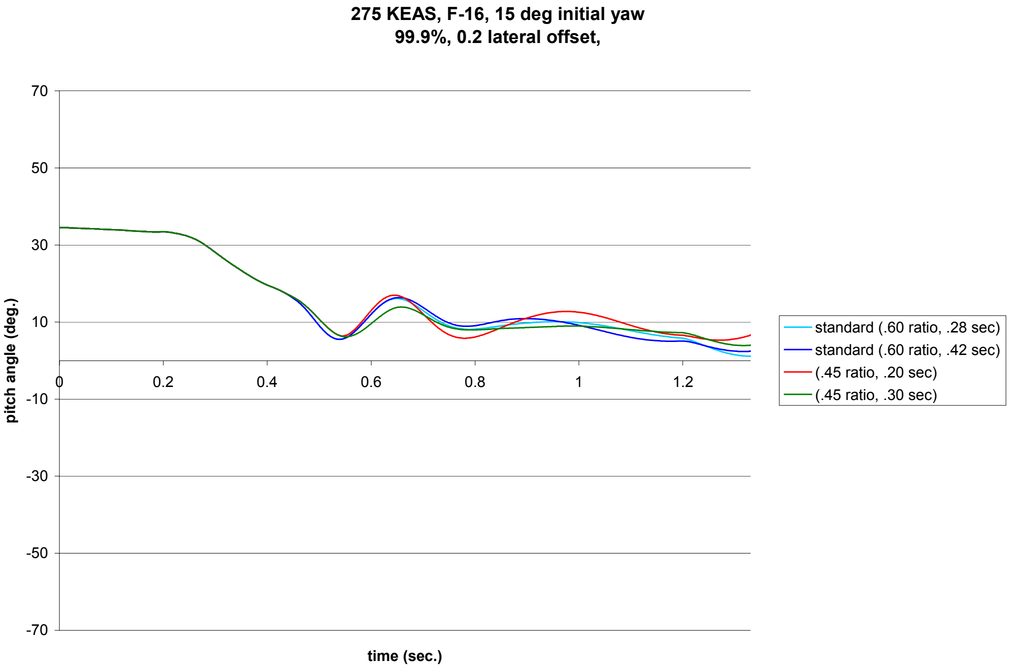


Figure 32. Pitch angle vs. time with an initial yaw of 15°

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 standard 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 tested four times in 2004 including two 600+ KEAS seat ejection tests.

Multi-seat Aircraft Optimization

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 33 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 34 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.

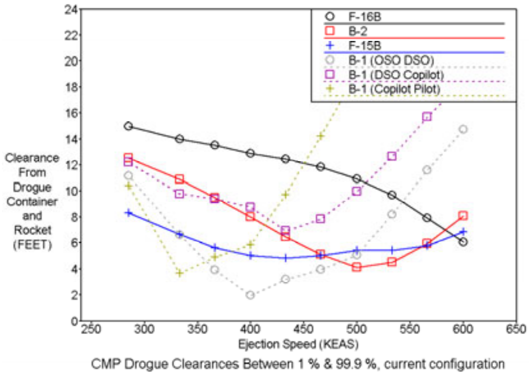


Figure 33. Tractor Rocket Clearances

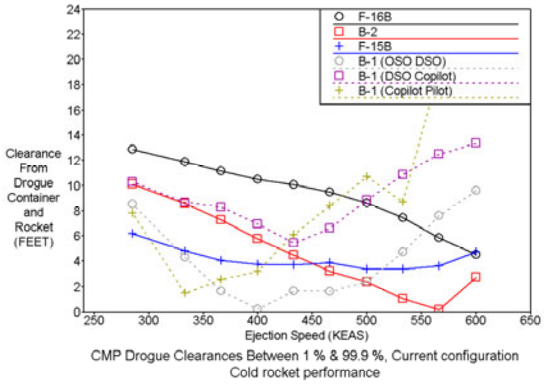
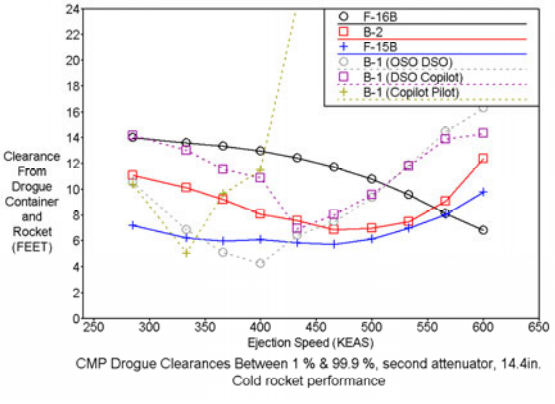


Figure 34. Tractor Rocket Clearances, with Cold CKU Performance

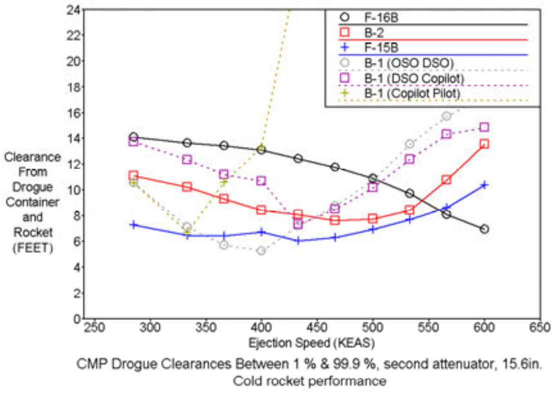
As Figure 34 above shows, if the worse case occupant combination is encountered while the CKU-5 catapult is temperature soaked at the lowest allowable temperature, a collision risk will exist for the B-1 and B-2 at certain velocities. To mitigate this risk, a second attenuator connecting the rocket/container to the drogue parachute would 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 assume the same attenuator material as the current primary attenuator in various lengths up to 24 inches. Figures 35 through 38 show rocket assembly clearances for various second attenuator lengths, velocities and aircraft. As stated before, this rocket collision avoidance method introduces risks to seat performance, which requires the selection of the minimum length attenuator with the maximum benefit and least amount of additional risk possible. The optimum attenuator length that provides the most clearance possible for all aircraft is 15.6 inches. Figures 36 shows the theoretical impact of a 15.6 inch, second attenuator on MDRC for a range of ejection velocities.



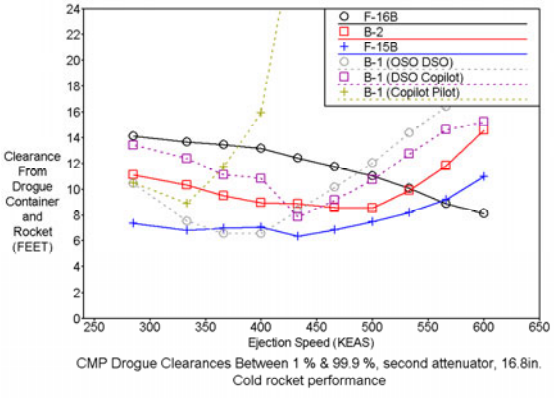
CMP Drogue Clearances Between 1 % & 99.9 %, second attenuator, 14.4in.
Cold rocket performance

Figure 35. Tractor Rocket Clearances, with Cold CKU Performance, and 14.4in Attenuator



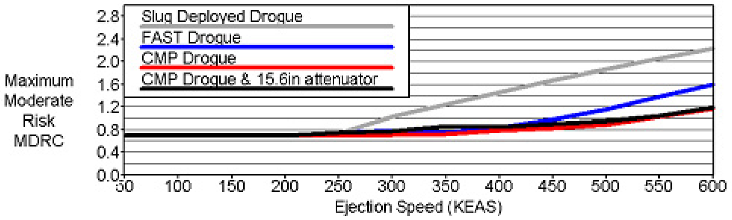
CMP Drogue Clearances Between 1 % & 99.9 %, second attenuator, 15.6in.
Cold rocket performance

Figure 36. Tractor Rocket Clearances, with Cold CKU Performance, and 15.6in Attenuator

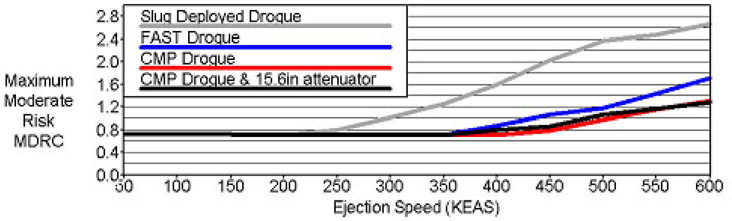


CMP Drogue Clearances Between 1 % & 99.9 %, second attenuator, 16.8in.
Cold rocket performance

Figure 37. Tractor Rocket Clearances, with Cold CKU Performance, and 16.8in Attenuator



Human Tolerance Comparison, ACES II F-16
Altitude 4000 ft, 1%, Lateral Offset 0.25



Human Tolerance Comparison, ACES II F-15
Altitude 4000 ft, 1%, Lateral Offset 0.25

Figure 38. MDRC Comparison with Standard and Enhanced Drogue with and without 15.6in Attenuator

Figures 39 and 40 show seat yaw, with an initial aircraft yaw of 15 degrees, for 1 and 99.9 percentile occupants for the standard slug deployed drogue, the current configuration of the enhanced drogue, the proposed enhanced drogue reefing configuration, and the new reefing configuration with a second attenuator. As can be seen in the figures, there is a significant improvement in stability by replacing the standard slug deployed drogue with the enhanced drogue system. They also show the decreased stability performance introduced by the second attenuator. The slight decrease in stability results in slightly higher MDRC (approximately 0.06), see Figure 36.

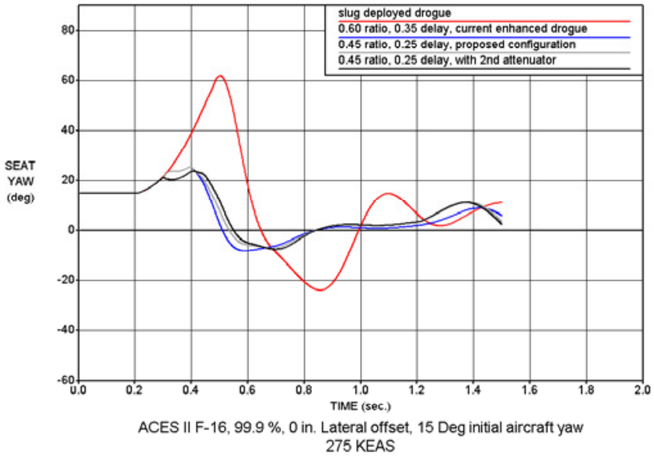


Figure 39. Seat Yaw Comparison with Standard and Enhanced Drogue with and without 15.6in Attenuator

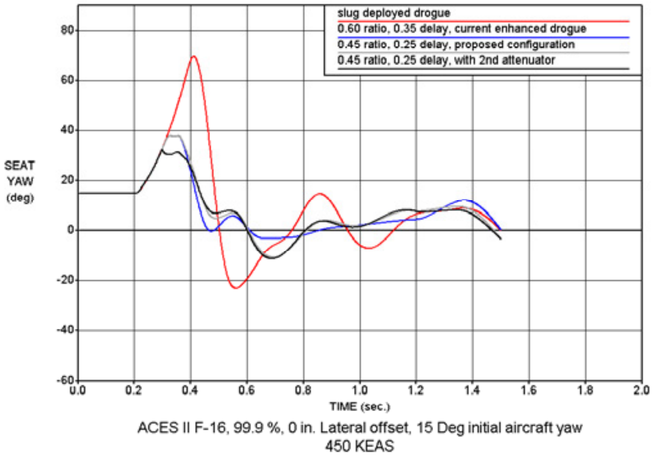


Figure 40. Seat Yaw Comparison with Standard and Enhanced Drogue with and without 15.6in Attenuator

Theoretical MDRC with enhanced drogue and 0.20 inch lateral offset			
KEAS	**15.6 in. attenuator**	**F-16, 1%**	**F-16, 99.9%**
600		1.37	1.12
600	2nd attenuator	1.39	1.12
450		0.90	0.75
450	2nd attenuator	0.96	0.76
275		0.62	0.64
275	2nd attenuator	0.65	0.65

Figure 41. MDRC Comparison of Enhanced Drogue with and without 15.6in Attenuator

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 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 in late 2004.

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-XXX-01 F-15 leg restraint retrofit kit and the 1847-XXX-01 F-16 leg restraint retrofit kit are on schedule for completing qualification allowing USAF fielding activities to begin in 2005.

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 that current and future escape systems must accommodate. Additional, 600 KEAS ACES P3I sled tests are scheduled in 2004. Pending successful results of the tests, the design will be ready to enter a subsequent qualification program.

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BIOGRAPHIES

Capt Demetrius Stewart is the program manager for the ACES II improvement program(s) at Brooks City-Base Texas. He has been doing program management for the last four years, including a previous assignment at Wright Patterson AFB where he worked in the B-2 System Program Office. Prior to his acquisition experience, he was a maintenance officer stationed at Barksdale AFB in Louisiana, working in the AGM-142 missile shop and as the 2nd Bomb Wing Munitions Accountable Systems Officers. Demetrius graduated from Grambling State University with a BS in Electronics Engineering Technology in 1996.

Mr. Benjamin Sabo is a project engineer for the ACES II Program at Goodrich-UPCO. Ben is currently the lead engineer on both phases of the ACES II Pre-Planned Product Improvement (P3I) Programs as well as the ACES II OBOGS Update Program. Ben graduated from the University of Michigan – Ann Arbor with a BSME in 1998.

Mr. Will Cromer joined Goodrich -UPCO in December 2000 as a project engineer to support the Seat Improvement Inflatable Restraint System and the conclusion of the Aircrew Stabilization Improvement Task. Previously Will designed the Cockpit Airbag System for the OH-58D Kiowa Warrior. Prior experience includes design work on the Eastern Test Range telemetry and control antenna, training curriculum development for expendable launch vehicles, ten years in support of nuclear submarines, and research and development in alternative energy. Will graduated from the University of Central Florida with a BSE in 1983. He completed a Master of Engineering degree at the University of Idaho in 1998.