MOBILE AIRCREW RESTRAINT SYSTEM - MARS

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ABSTRACT

For several decades, aircrew working in the cabin of military helicopters have used a simple nylon chest strap with an adjustable tether, commonly called a "gunner's belt", as their fall protection system. The chest strap is donned and the tether is clipped to various anchor points in the cabin in order to provide fall protection. However, aircrew have been thrown out of the aircraft during mishaps, when using this configuration. This paper discusses the development of a system that provides a substantial improvement in fall and crash protection. The system consists of a webbing retractor that mounts to the aircraft cabin ceiling, extending and retracting webbing as the aircrew moves about the cabin. Attached to the retractor mount is a modified gunner's belt with a shorter tether. Should the aircraft crash or the aircrew fall, the retractor locks, preventing further webbing extraction. By preventing slack from developing, and proper location of the retractor within the aircraft, the system significantly improves the likelihood the aircrew will remain within the cabin. Additional work is underway to eliminate the gunner's belt completely by utilizing the lifting harness already worn as part of the AIRSAVE survival vest, thus distributing the crash or fall loads over the aircrew member's body.

INTRODUCTION

Mobile aircrew of military helicopters are arguably at the greatest risk of injury of all helicopter crewmembers. They are required to move about the cabin of the aircraft during nearly all stages of flight, frequently leaning out of open cabin doors. Currently, the restraint system used consists of a nylon strap buckled around the chest and an adjustable tether that is hooked into tie down rings in the cabin structure.

Several mishaps resulting in fatal injuries to mobile aircrew have recently occurred when aircrew were ejected from the aircraft upon crash impact or evasive maneuvers. The tether of the current restraint system is adjustable from approximately two to six feet, and is usually extended to the longest length to allow maximum mobility for the aircrew to perform his/her mission duties. In a mishap environment, this amount

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of slack allows substantial excursion of the aircrew outside the aircraft, greatly increasing the risk of injury.

The U.S. Navy and H. Koch and Sons, Inc. are currently working to develop a webbing retractor system (the “Mobile Aircrew Restraint System”, or “MARS”) to reduce these injury mechanisms. A standard MA-16 gunner’s seat reel has been modified to increase strap payout and to mount to specific locations in the cabin ceiling. If the aircraft impacts the ground or an aircrew member falls from or within the aircraft, the retractor locks, preventing any significant excursion from the aircraft. Additionally, any movement of the aircrew towards the retractor causes webbing to be retracted, thereby reducing the tether length and the associated strike envelope.

Extensive use of computer simulations uncovered that even with zero slack in the restraint system, complete body excursion from the aircraft is likely if the anchor point is improperly located. Simulations identified retractor mount locations that provide optimum restraint of the aircrew so that he/she remains within the cabin.

To date, numerous crash simulations, Horizontal Accelerator crash tests, and drop tests have been conducted to evaluate the webbing retractor system. Ground evaluations and flight tests were performed at Naval Air Station North Island, California, NAS Fallon, NV and NAS Patuxent River, MD. All tests and evaluations have proven favorable. Final preparations are currently underway to deploy the system into the H-60 B/F/H series of helicopters.

SYSTEM COMPONENTS AND REQUIREMENTS

The MARS system is comprised of two main components: the webbing retractor and the crewmember safety belt (“CSB”, also known as the “gunner’s belt”). The program originated with the intent of using non-developmental items for use in the MARS system. Therefore, the components were not designed specifically for this application; they are modifications of existing items. The modifications are minor, yet have proved to be sufficient to meet all performance requirements.

Webbing Retractor

The webbing retractor design is based on the MA-16 inertia reel. MA-16 inertia reels are qualified for use on military aircraft for seat restraint applications, and are widely used in rotorcraft as well as some fixed wing aircraft. The MARS is derived from a special class of MA-16 inertia reels used for gunner seats in Army and Navy H-60 aircraft. The gunners inertia reel was especially well suited for the MARS application because its housing accommodates a larger amount of webbing, which is important for mobile restraint.

For the MARS system, the modified retractor is mounted in the ceilings of H-60 series of aircraft. Mounting holes already exist (known as “red ring holes”) for mounting various pieces of equipment to the helicopter. The retractor mounts directly into these red ring holes via a single bolt. A thrust bearing is threaded to the bolt and sits flush against the ceiling structure of the aircraft in order to reduce the bending moment, in turn, meeting strength requirements. In the case of the HH-60H, an additional set of holes are fabricated for the MARS system for the aft section of the aircraft. A “MARS bar” that houses one retractor has also been fabricated and is installed when the forward troops seats are removed. This bar is fastened to the mounting brackets for the troop seat bar via two bolts.

The mobility needed by the aircrew requires more webbing with the MARS system than could be accommodated by the existing retractor with nylon webbing. Kevlar webbing replaces the nylon since it is approximately half the thickness of the nylon. With this change, the retractor could accommodate enough webbing for aircrew requirements. Environmental testing demonstrated Kevlar degrades less over time than does nylon.

Since the webbing will rub against objects in the cabin, and possibly the edge of the cabin floor if the aircrew member should fall, cut and abrasion resistance was critical. Standard abrasion tests for fabric were conducted, and Kevlar was comparable or better than nylon. To test cut resistance, samples of Kevlar webbing were pulled over sharp edges. Half of the samples had 1/4-inch notches cut into them to initiate tears. In all cases, the webbing exceeded the required strength.

A larger spring was required to retract the additional webbing. The spring also needed to have a stronger retraction force to prevent slack from forming as the aircrew moved within the cabin. A new spring was found, and a slightly larger spring cup on the retractor was produced to house it. With the larger spring installed, the spring tension has increased, thus increasing the force to extract the webbing. This increase in spring force will be scrutinized during our continuation efforts with the AIRSAVE interface.

During evaluations at Naval Air Station North Island, California, where mobility requirements were being determined, it was discovered that the acoustic panels in the ceiling tend to sag over time. The sagging panels could interfere with the free rotation of the retractor, needed to prevent twisting of the webbing as the aircrew member moved. A simple solution was found by employing an aluminum retaining ring mounted above the retractor in order to hold the acoustic panel in place to avoid interference with the rotating MARS retractor. The retaining ring and retractor are shown in Fig 1.

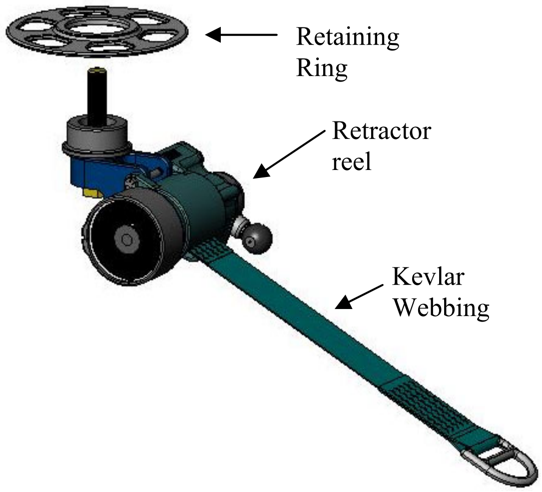

Fig. 1: Webbing retractor-RMU-42/A

Modified Crewmember Safety Belt (MS16070-21/A)
The current standard crewmember's safety belt (a.k.a. "gunner's belt" or CSB) consists of a wide nylon strap with an incorporated buckle, which is worn around the chest. A nylon tether extends from the back of the chest strap, and is adjustable in length from approximately two to six feet in length. In use, the tether is normally left at its maximum length so that the aircrew does not have to constantly adjust its length as he/she moves about the cabin. At the free end of the tether is a hook with a sliding gate, which clips into triangular rings in the cabin ceiling.

There are several deficiencies with the current belt. One shortfall is the difficulty to operate the sliding gate on the hook while wearing flight gloves. Another being the lack of safety when aircrew move more than six feet into the cabin they must disconnect from one anchor point, walk unrestrained to the next location, and clip into another anchor ring. Additionally, the chest strap produces concentrated loads on the chest during crashes or falls, increasing the risk of injury. Often, the belt is worn around the abdomen, increasing the risk of injury even further.

The MARS modified crewmember's safety belt is the standard belt currently in use by the Navy, but with two modifications. The slide adjuster has been removed from the tether, the tether has been shortened and the hook was replaced with a hook easily operated by one gloved hand. The hook has an integrated swivel to prevent the tether and retractor webbing from twisting. The Fleet chose this hook after several commercially available hooks were presented to them to choose from. The tether of the MARS modified belt is double-layered to provide better cut and abrasion resistance.

Fig. 2: Crewmember Safety Belts: MARS belt (top) and standard belt (bottom)

Fig. 3: Detail of standard CSB hook (bottom) and MARS CSB hook (top)

PERFORMANCE REQUIREMENTS

The basic concept of the MARS system is straightforward: improve the crash and fall protection of mobile aircrew without hindering their mission duties. This created several parameters that needed to be addressed:

- System strength
- Retractor mounting locations

- Amount of webbing needed to allow required aircrew mobility
- Retractor locking sensitivity
- Single-handed operation
- No snag hazards for emergency egress

The required system strength was of paramount concern. To determine the required strength, a worst-case fall situation was considered: a 300-lb aircrew falling six feet straight down. This represented a 95th percentile male aircrew with flight equipment and body armor falling the total length of the standard gunner's belt. Computer simulations and subsequent dynamic tests, determined that the maximum load on the system was approximately 3,300 lbs. The standard 150% safety margin produced a strength requirement of 5,000 lbs. This is the same requirement used in the fall protection industry, therefore commercial off-the-shelf hardware were readily available.

Placement of the retractor within the aircraft cabin is critical to the performance of the system. If, for example, the retractor is located very close to the cabin door, the aircrew will still be thrown clear of the aircraft, even if there is no slack in the webbing. Figures 4a-c show computer simulations of a 20G vertical, 10G horizontal crash of an SH-60. The pictures are of a crewman at maximum excursion from the aircraft at opposing anchor locations and two different tether lengths (full extension and no slack). The gray outline is the cabin, as seen along the axis of the aircraft, looking directly rearward. Clearly, placement of the retractor is critical, as is the amount of slack.

To locate the optimum placement for the retractors, extensive use of computer simulation proved invaluable. A model of the cabin was made, and a grid of 24 anchor points was incorporated. The retractor was located at each anchor point in succession, and several crash pulses were simulated. The kinematics of the model's aircrew were then evaluated and rated as good, moderate, or poor. From these simulations, zones of good, moderate, and poor anchor locations were mapped. Using this zone map, locations in actual aircraft that had sufficient structural strength, did not have obstructions that would interfere with the retractor and were compatible with mission needs, were then identified.

Once the locations of the retractors were determined, the amount of webbing needed to allow the aircrew to perform their duties was easily found. Crewman simulated all mission performed during flight through ground testing at Naval Air Station North Island, California. The amount of webbing extracted was recorded for each task, and the maximum length extracted determined the amount needed in the retractor.

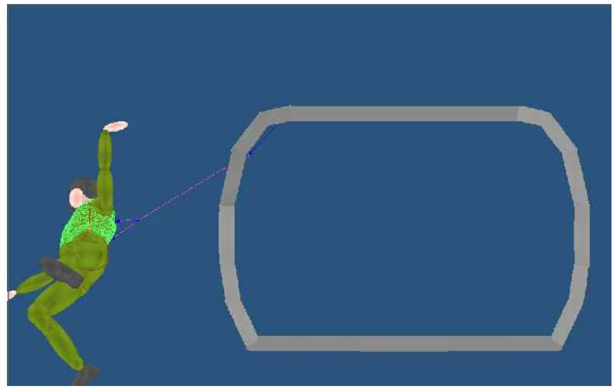

Fig. 4a: Computer simulation of standard CSB (at full length) anchored near cabin door

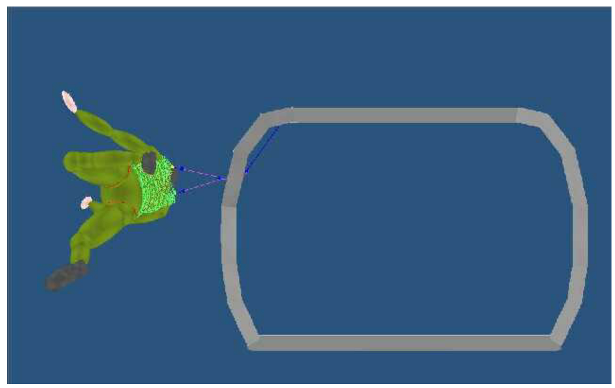

Fig. 4b: No slack in same location as Fig. 4a

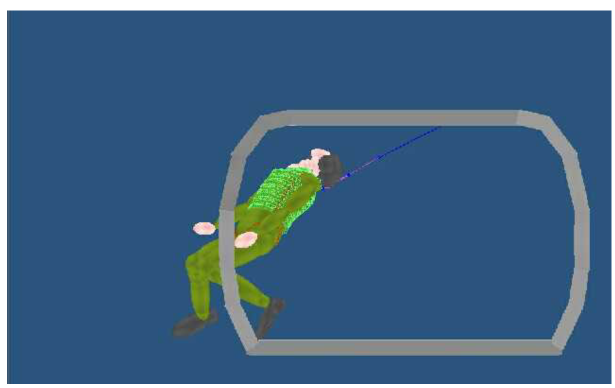

Fig. 4c: No slack in optimum location

Both vehicle acceleration and webbing payout acceleration causes the retractor to lock. During ground tests, the level of sensitivity for fall protection was determined. The webbing payout calibration must be very sensitive in order for the retractor to lock as soon as the crewman falls. However, if the retractor is too sensitive, it will lock when crewmen move quickly throughout the cabin, performing his/her duties. More than a nuisance, this inadvertent locking can be a safety risk if it occurs at a critical time.

Finally, the crewman must be able to release from the restraint with a single motion of one hand; this is critical in naval helicopter safety. Helicopters tend to sink very quickly after impacting the water. A crewman holding his/her breath under water would be at risk if the release sequence requires extra time to perform multiple movements. After releasing from the restraint, there should not be webbing or fittings remaining attached to the aircrew member that may snag on objects, possibly impeding or elongating egress. The current crewmember safety belt and the modified MARS version excel in ease of egress. Either hand easily operates the single latch on the chest strap, releasing the restraint from the person.

TESTS AND TEST RESULTS

The MARS webbing retractor and modified crewmember safety belt are essentially the same as the current in-use items, therefore, only a "delta qualification" test program was required. However, since both have been modified and the retractor will be used in a different application, testing was conducted to ensure the system would perform as intended. The tests included:

- Environmental
- Static strength
- Cut resistance
- Dynamic (drop tests and horizontal accelerator)
- Ground evaluations
- Flight tests

The environmental tests were conducted on the Kevlar strap and the new snap hook for the crewmember safety belt. The other components of the standard retractor and CSB are already qualified. Tests included salt and fog immersion, ultraviolet light exposure, etc. The results demonstrated Kevlar performing better than the standard nylon used in the CSB.

Static strength tests require the entire system be capable of supporting a 5,000-lb load for three seconds. While the retractor is already designed for that load, the method in which the Kevlar strap fits into the spool shaft had to be modified. Normally, in seated-occupant applications, there are always a few wraps of webbing around the spool shaft that lessen the load on the fitting on the end of the strap. However in the MARS system, it is possible for the webbing to be fully extracted with no wraps of webbing left around the shaft, therefore, the end fitting would be subjected to the entire load. Thus, the end fitting was redesigned and the retractor passed all strength tests.

Since the webbing will be subjected to rubbing against objects and structures inside the aircraft, it was important to test the cut resistance of the webbing. The CSB was modified by doubling the layers of webbing on the tether strap in order to provide more cut resistance, however, the Kevlar was single-layered. A test fixture was implemented that stretched the webbing (both Kevlar and nylon) over a metal block that was shaved down to represent the worst-case edge in the aircraft that may cut the webbing (as shown in Fig. 5). The block was placed in a clevis and a hydraulic piston raised it, increasing the load on the strap. For some tests, a 1/4-inch notch was cut crosswise in the strap and positioned directly over the edge of the block. This was intended to initiate a tear in the webbing. In all cases, the webbing withstood twice the 5,000-lb strength requirement without failure.

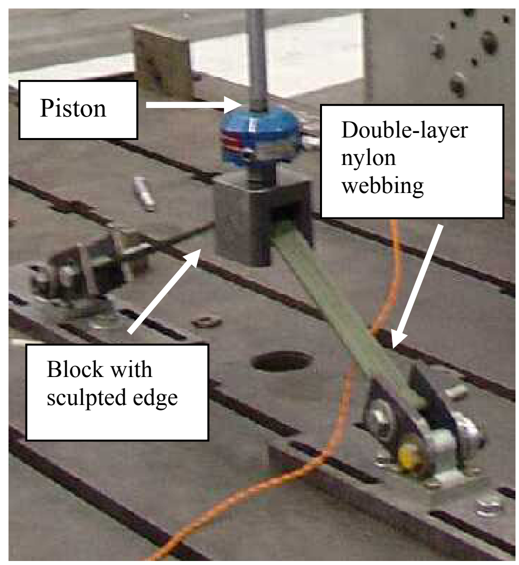

Fig. 5: Cut resistance test fixture

Drop testing was performed to simulate a crewman falling out of the cabin. The webbing Retractor was mounted to an I-beam twenty feet above the floor of the laboratory. The test dummy was raised to various to heights to simulate different amounts of webbing payout prior to dropping. The modified CSB was then connected to the retractor and the dummy was attached to a tether that opened a quick-release buckle, letting the dummy drop. The test configuration is demonstrated in Fig. 6. A 5^{th} percentile female (approximately 108 lbs) and a 50^{th} percentile male (approximately 185 lbs) test dummy were used. The retractor locked for all twelve tests conducted. Webbing payout varied from approximately 10 to 34 inches; the more webbing on the spool prior to the drop, the more webbing was paid out prior to the retractor locking. This was as expected, since more webbing on the spool decreases the spool's acceleration, therefore, delaying lock of the retractor. In all cases, injury data were within human tolerance.

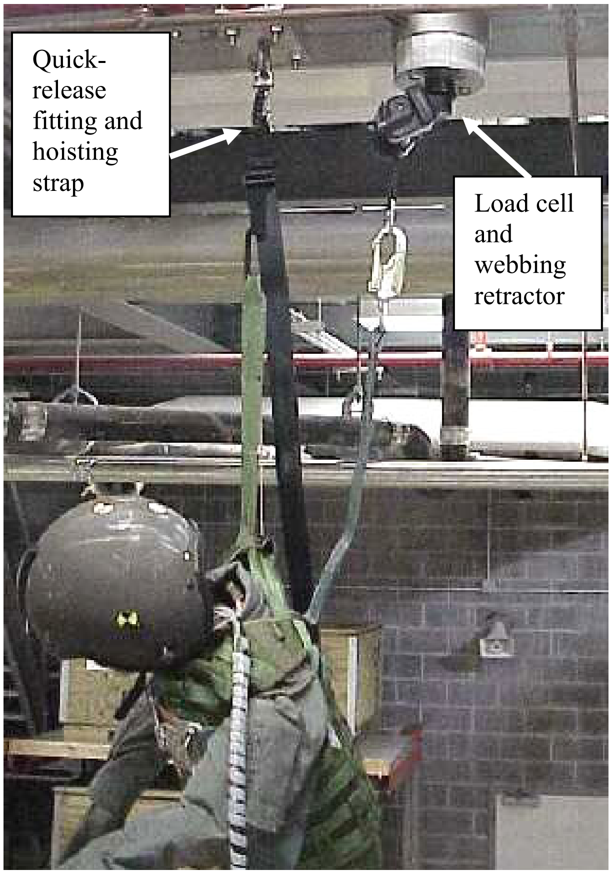

Fig. 6: Drop testing (small female dummy, prior to test)

Crash simulation tests were conducted at the Horizontal Accelerator Facility at NAS Patuxent River. A sled was accelerated along rails, simulating a 10 G, 32 ft/sec crash pulse. A 95th percentile male (approximately 250 lbs) and a 5th percentile female (approximately 108 lbs) test dummy were used in several test configurations. This crash pulse represents a moderate impact for seated occupants, but near the limit of what can be expected to be survivable by an aircrew member on a tethered restraint such as the MARS system. The test dummies were positioned at different distances from the retractor and in either forward facing or side facing orientations (as shown in Fig. 7).

Chest compression and neck loads of the test dummies were high in most cases, but this was not unexpected, and comparable to the current CSB used by aircrew. Multiple impacts could not be tested, but tests were conducted in which the test dummy was accelerated towards the retractor and passed underneath it. With the current belt, the dummy would pass under the retractor and continue for the entire length of the belt, approximately six feet. Severe injury potential would ensue due to acceleration loads as well as the increased strike envelope. The MARS system, however, successfully retracted the webbing as the dummy moved towards the retractor, so that the dummy moved only about two feet past the retractor. This results in lower injury potential compared to the current safety belt. An additional test placed the large male dummy at 100% webbing payout, so that the interface fitting of the webbing to the retractor spool was the sole part reacting the load. In this test, as with the others, there was no structural failure of any component.

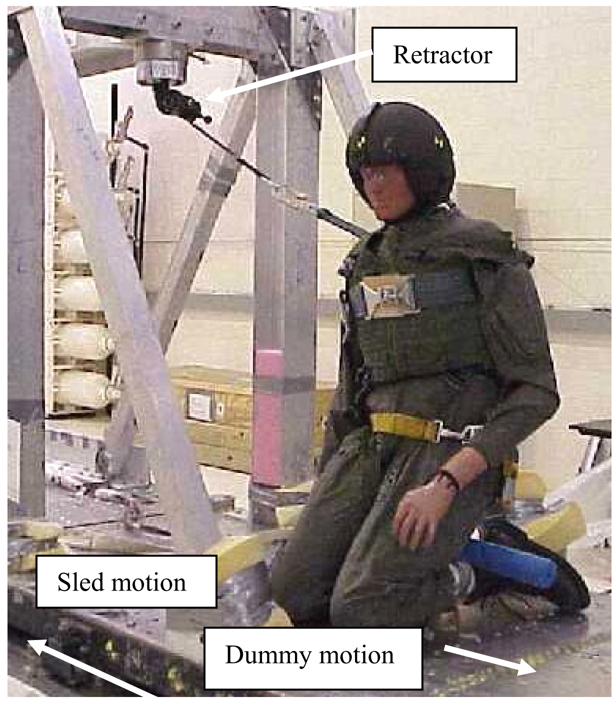

Fig. 7: Horizontal Accelerator Test (Large male dummy, side facing orientation)

Flight tests have been conducted on the H-60 B/F/H/S models. The flights were held at NAS Fallon, NAS North Island and NAS Patuxent River. During the Fallon evaluation, the MARS system was flown in the HH-60H for 4 weeks and evaluated by the Fleet. The crewmen were very pleased with the system and did not have any negative feedback besides the mention of occasional nuisance locking. The Fleet did not see this as a hindrance to their mission duties. The sensitivity of the retractor was lowered, however, in order to mitigate the nuisance locking issue. Since this recalibration, the drop tests were re-evaluated at this lower setting in order to ensure the retractor would still lock if an occupant were to fall. All tests were successful. It should be noted that the nuisance locking was only apparent during flights and not as much in ground tests.

This highlights the need for flight-tests whenever possible, plus a high level of fidelity in all tests. During flight test at NAS Patuxent River, the crewman experienced fatigue after using the restraint system for an elongated amount of time. Since this test, the pre-tension on the power spring has been lowered in order to reduce the amount of force needed to extract webbing. However, the spring force is still high enough to fully retract the webbing, as needed. This change in spring force has been re-evaluated by the same crewman and they experienced a much lower level of fatigue. Fig 8 shows a crewman simulating mission duties during a ground evaluation at NAS Patuxent River, MD.

Fig. 8: Crewman during ground evaluation

CONCLUSIONS

The development of the MARS system required a significant integration effort. The work done early in the program helped to preclude problems when the system is introduced to the Fleet. Repeated input from Fleet aircrew proved invaluable for the engineers to understand what is needed, and to provide the best product possible. The feedback also helped ensure that aircrew, who will need to use the system on a daily basis, have a system that fits their needs and works as they would like. Simple things such as having aircrew provide input as to which snap hook was preferred and whether the retractor spring tension was too strong are easy to accommodate, yet provide large benefits towards supplying a better system for the end user.

Computer modeling and simulation provided a valuable insight towards locating the retractor in the best possible locations. Given the highly dynamic environment of this system, being able to see the kinematics of various crash/fall scenarios proved to be a tremendous benefit.

Test data proved that Kevlar, while thinner than nylon, is nevertheless well suited for this application. During environmental testing, Kevlar was shown to be more resilient to cut resistance and UV/salt fog degradation than Nylon. Drop tests demonstrated that fall distances are less than half of those with the current safety belt; this reduces injury likelihood and also facilitates the aircrew getting back inside the aircraft.

Crash tests show that use of the MARS system reduces the likelihood of injury. By not allowing slack to be present, the webbing retractor reduces dynamic overshoot as the aircrew reaches the end of the tether during the crash sequence. Additionally, by retracting webbing whenever the aircrew is thrown towards the retractor (during multiple-impact crashes), the strike envelope is reduced.

While the MARS system cannot replace a proper crashworthy seat, it does provide a significant improvement to aircrew crash protection for mobile aircrew members.

The MARS system is scheduled to be deployed into the legacy H-60 platforms (B/F/H) staring in January 2006.

CONTINUATION EFFORT

As a follow-on effort, work is also underway to eliminate the gunner's belt completely and attach the webbing retractor directly to the lifting harness in the AIRSAVE survival vest already used by the aircrew. By integrating the retractor system to the lifting harness, if a crewman were to fall, the loads will be distributed throughout the lifting harness as opposed to being concentrated on the chest, like that of the gunner's belt.

The AIRSAVE survival vest worn by Navy aircrew has a lifting harness incorporated into it, which encompasses the shoulders, legs, and buttocks of the aircrew. Clearly, it would be preferred to use this body harness instead of the chest strap of the current safety belt. Work is underway to produce a prototype system that would clip the webbing retractor to the shoulder loops of this harness, eliminating the need for the current chest strap completely. A major difficulty with this integration is allowing for a single-handed, one-motion emergency release (critical for underwater egress). Another hurdle is ensuring that the interface between the webbing retractor and the body harness allows for the webbing's stretch and movement of the harness during dynamic loading. In a separate program, the Navy is developing several prototype systems to integrate with the lifting harness. When complete, this AIRSAVE interface will replace the modified safety belt described above.

The prototype has been tested in a simulated underwater helicopter cabin "dunker" at NAS Pensacola, FL. After a minor design revision, testing was successful and crewman were able to easily egress from the inverted dunker, underwater. Integration efforts have begun on the H-53E, H-60R and H-60S for this MARS-AIRSAVE interface.