Status of the Development of an Autonomously Guided Precision Cargo Aerial Delivery System

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The US Army Natick Soldier Center (NSC) is currently engaged in the development of a family of modified high altitude - low opening (HALO) autonomously guided precision cargo aerial delivery systems. In alliance with the US Joint Forces Command and the US Air Force Air Mobility Command, DUSD-AS&C, the NSC including PM-FSS and Strong Enterprises, has engaged in the design and development of an autonomously guided 2000 lbs. and 10,000 lbs capable high glide delivery system, which has been successfully demonstrated in weight ranges 500 lbs. through 10,000 lbs. GRW. This platform known as SCREAMER is currently being tested at system design weight of 10,000 lbs GRW from military C-130/C-17 aircraft at the US Army Yuma Proving Ground, Arizona.

Nomenclature

ACTD	=	Advanced Concepts and Technology Demonstration
AGL	=	above ground level
AGU	=	airborne guidance unit
AMC	=	Air Mobility Command
AOD	=	automatic opening device
CARP	=	computed aerial release point
COCOM	=	combatant commander
CONOPS	=	concept of operations
DoD	=	Department of Defense
DUSD-AS&C	=	Deputy Under Secretary of Defense for Advanced Systems Concepts
ECDS	=	Enhanced Container Delivery System
FY	=	fiscal year
GRW	=	gross rigged weight
GN&C	=	guidance, navigation and control
HALO	=	high altitude low opening
IP	=	point of impact
JFCOM	=	Joint Forces Command
JPADS	=	Joint Precision Airdrop System
L/D	=	lift to drag ratio
MROS	=	mobile remote operator station
NSC	=	Natick Soldier Center
PM-FSS	=	Product Manager Force Sustainment Support
RAD	=	ram-air drogue
US TRANSCOM	=	US Transportation Command

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I. Introduction

This paper will present the results of work conducted by the US Army Natick Soldier Center (NSC) in the ongoing development of a modified HALO autonomously guided precision cargo aerial delivery systems in support of the Joint Precision Airdrop System (JPADS). In collaboration with the US Joint Forces Command, the US Air Force Air Mobility Command, PM-FSS, DUSD-AS, the US Army Natick Soldier Center and Strong Enterprises, Inc., Orlando, Florida has engaged in the design and development of an autonomously guided high glide delivery system, which has been successfully demonstrated at weights up 10,000 lbs. This equipment ensemble being developed within the context of the Advanced Concepts and Technology Demonstration (ACTD) is known as SCREAMER and will be tested at the current system design weight of 10,000 lbs from C-17/C-130 aircraft at US Army Yuma Proving Ground throughout 2005.

The Army Vision 2010 recognized "improved methods of aerial delivery" as a crucial DoD requirement for the rapid deployment of warriors, munitions, equipment and supplies. Remote military operations necessitating deployment of troops in situations where they are cut off from their supply sources have spawned and continue to fuel the development of low cost, autonomously guided aerial resupply systems like SCREAMER. *(ref: 1)* This joint Army-Air Force initiative has entailed innovative decelerator design, advanced hardware and guidance software development, integration and implementation of unique deployment configurations and an overall system concept and reliability that is unprecedented in airdrop.

Figure 1. 10,000 lbs SCREAMER during recovery phase
The 10K SCREAMER immediately following the dual G-11 recovery parachute deployment showing RAD still inflated, recovery mantle, and ECDS-based payload.

This airborne delivery system is gravity deployed from the ramp of cargo transport aircraft. The ram-air drogue (RAD) parafoil inflates immediately upon exit from the aircraft and in a very brief maneuver, the onboard guidance unit commands a sequence of routines in order to establish control and autonomous flight in a straight line navigation mode en route to the target or first programmed waypoint. Upon reaching a point in space above the target area, a round or cluster of round recovery parachutes is deployed several hundred feet above ground level to arrest high trajectory speeds in excess of 120 mph and affect a ballistic soft landing of less than 24f/s rate of descent. The actual point of recovery parachute deployment is resolved onboard in consideration of preloaded mission planning software incorporating knowledge of surface winds in a wind layer 0-500 feet AGL. This type of deployment sequence is unique, in that a parafoil is inflated directly after dispatch from the aircraft and incorporates a final stage sequence of round ballistic recovery canopies. Even more exclusive to this system though, is the fact that the SCREAMER ram-air canopy is typically loaded to 15 lbs./ft^2 of supporting fabric surface area in the 10,000 lbs. configuration, ten-to-1 wing-loading in the 2200 lbs configuration, giving it a forward velocity easily capable of penetrating 60 knot winds. Unprecedented opening forces and wing load on the parafoil have spawned the design of a very durable and survivable canopy. Design sensitivity to component commonality and a unified configuration throughout the family of SCREAMER systems has resulted in a low cost, modular, easily recoverable delivery system that utilizes many components already in the US Army inventory. Currently the SCREAMER system is being tested at 10,000 lbs. utilizing a 650-ft^2 ram-air drogue (RAD) and a pair of 100-foot diameter standard Army G-11 cargo recovery parachutes. To date more the 100 fully autonomous flights have been conducted with SCREAMER systems at test ranges in western Arizona.

II. Sustainment of Military Forces and JPADS

Strategic, operational, and tactical employment of forces in the contemporary operating environment requires a change in the way the military sustains its forces. The time and place of the next battle is unknown. Military planners are no longer able to define the next area of operations with certainty and, thus, carefully prepare by strategic forward positioning of forces, equipment, and stocks. Gone are the days when forces could be forward-positioned to meet the threat. In the contemporary operating environment, adversaries have the ability to threaten interests or attack with little or no warning. Additionally, the adversaries have changed. Sensing the futility of opposing conventional US forces, they attempt to gain the initiative by conducting asymmetric operations using wide dispersion in remote, rugged, and/or unmanageable terrain to counter mobility and information superiority. Adversaries have developed tactics, techniques, and procedures that result in significant disruption of US operations. Rocket-propelled grenades down helicopters; vulnerable lines of communications are disrupted by improvised explosive devices and direct action. These two significant changes (strategic warning and asymmetric operations) in the strategic environment are effecting changes in the way US forces must deploy and employ forces.

To provide maximum agility and flexibility in response to global contingencies, US forces will increasingly deploy from the strategic base of the US. Current joint guidance states that forces must be able to rapidly deploy, immediately employ upon arrival in the theater of operations, and be continuously sustained throughout the operation. New technologies enable US forces to maneuver against a dispersed enemy in a distributed, non-linear, and non-contiguous fashion. These forces can operate cohesively and maintain situational awareness even while separated by long distances. However, these operations outpace the ability of logistics. The current sustainment distribution system is incapable of responding globally to a dynamic tactical environment from operational and strategic distances. It is a slow, indirect, complex, resource-compounding system that is tied to known choke points: Aerial Ports of Debarkation (APODS), Sea Ports of Debarkation (SPODS), large Drop Zones (DZ), and Ground Lines of Communication Supplies (GLOCS) and equipment generally reach users in days or weeks rather than in hours. JPADS is to provide a global delivery system capable of 24-hour fort (continental US) to fighter (unit/teams) distribution *(Fig. 7).*

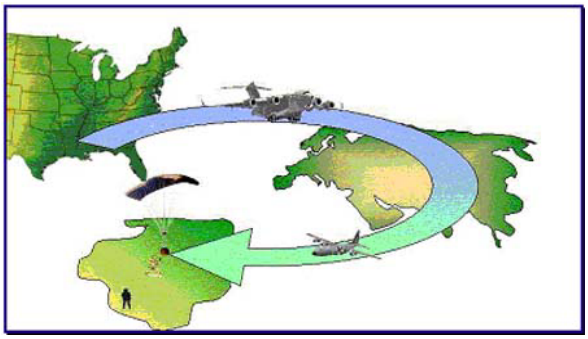


Figure 2. JPADS CONOPS: *JPADS will deliver required materials to the warfighter within 24 hours without need of a complex mix of APODS, SPODs, and GLOCS.*

JPADS will provide a currently non-existent capability that reduces the time/distance paradigm, allowing sustainment of operational maneuver from strategic distances, reducing reliance upon forward APODs/SPODs, and promoting the ability to conduct early entry operations under denied access conditions. It is intended to reduce operational and logistic burdens associated with the infrastructure (e.g., personnel, ground vehicles, and ground vehicle support), which is required to provide a secure and effective logistics supply route. JPADS capability will significantly reduce the operational and logistic footprint required to support a Main Supply Route.
JPADS encompasses guided precision airdrop system that is more accurate than non-precision systems when delivered from high altitudes. The guided system benefits both from the Mission Planner computed air release point (CARP) and the ability of the payload to steer itself to a predetermined impact point. The JPADS capability is to provide an accurate airdrop delivery to keep the threat to the war-fighter at a minimum. (Ref: 2)

III. Chronology: SCREAMER Development

The SCREAMER concept originated in 1999. In a scaled demonstration, Strong Enterprises debuted a 14-ft^2 ram-air parafoil employed as a drogue parachute supporting a 220 lbs. payload. This 16:1 wing load demonstration was conducted at Lake Whales, Florida, dispatched from 13,500-ft MSL from a Casa aircraft with full trailing edge deployment brakes engaged. Immediately after canopy deployment a violent spin was induced prior to brake release that first demonstrated the difficulty that would be encountered attempting to maintain control of a parafoil with

such significant wing load. After stable, straight flight was established following brake release it was noted that extremely small toggle stroke of an inch or less, would induce swift responsive turns. Even at the current 10,000 lbs payload range using a 650-ft^2 ram-air parafoil, it is necessary to employ responsive turn-rate gyro input to the onboard system processors to achieve initial steering control. Once the system is in stable navigational-mode flight en route to the target or waypoint, turn control toggle stroke never exceeds 16", typically 4-inches or less. With forward velocity vectors in relative winds exceeding 70 mph, it became apparent that penetration of higher intensity upper level winds would be a distinct advantage along with short transit times from aircraft exit to touchdown, also making SCREAMER payloads less of a target on a non-permissive DZ.

Throughout CY2000 and CY2001, Strong Enterprises continued to conduct airdrop development tests of the SCREAMER system primarily at drop zones throughout Florida and during that period was awarded a small development contract by the US Army Natick Soldier Center, Natick, Massachusetts that would culminate in a demonstration of SCREAMER capabilities in the 700 lbs payload weight range at a US Army test range. At that time Strong engaged the technical support services of RoboTek Engineering, Gainesville Texas. Bruce Markle, vice-president of RoboTek worked hand-in-hand with Strong staff to develop a rudimentary guidance and navigational control system including a single motor actuator to control SCREAMER's RAD and a 900MHz ground station uplink with joystick operator control. Over the course of 80 drops, payload weights were increased from 200 lbs to 500 lbs, and in early December 2001, Strong Enterprises and RoboTek Engineering demonstrated 14 drops from a military UH-1 helicopter from 4500' above Sidewinder DZ, US Army Yuma Proving Ground, Yuma, Arizona. They successfully demonstrated successive 740 lbs GRW A-7A configured drops, manually controlled from the ground with the recovery phase initiated by an automatic opening device (AOD) employing a barometric pressure and rate of descent sensor that fired a pyrotechnic line cutter.

At that time Strong Enterprises proposed a follow-on development effort and was awarded a one-year best effort contract with the goal of demonstrating 4000 lbs payload capability by the end of the fiscal year 2002. By April 2002, a 1200 lbs gross rigged weight ground controlled r/c flight had been demonstrated. It became clear that summer, SCREAMER evolution has out paced sufficiency and safety afforded at commercial drop zones in Florida commonly used by Strong. In July of 2002, drop testing resumed on a dry lakebed in northwest Arizona with base of operations located at the Mohave County Airport in Kingman, approximately 40 miles south. From that time forward all SCREAMER development tests were conducted over Red Lake DZ from altitudes of 15,000' MSL from a commercial C-123K former military plane. Typical deployments were at airspeeds of 110-120 kts from the ramp.

Figure 3. *8000 lbs. SCREAMER load ready for deployment from C-123 over Red Lake DZ, Kingman, Arizona*

At this time it was decided to design future SCREAMER configurations to make maximum utilization of assets on hand in US Army inventories and the standard G-12 military cargo parachute was adopted as the recovery canopy. This would help control system acquisition cost and eliminated the need for special rigger training. During this development year, payloads were rigged with instrumentation including multiple load cells located in both riser load paths to record RAD opening dynamics, wind speed and baro-sensors to log rate of descent and GPS sensors to track forward speeds and flight tracks. Onboard video and ground-to-air video documentation was also provided.

During the FY2002 development year, two SCREAMER canopies were developed and tested to cover the 500-4000 lbs. payload range. A 220-ft^2 and 425-ft^2 ram-air drogue was designed and 5 initial copies of each produced to begin testing. In an attempt to verify the durability of the design and fabrication techniques, the RAD was stress tested to nearly 20:1 wing loading during the course of tests that year. Expectations of structural failure were foiled when it survived repeated explosive inflations during deployments from 10,000 feet. Flight dynamics were less than ideal. Although flight performance on those airdrops was not the objective, canopy design and methods of RAD construction boldly survived unprecedented loads for a parafoil, easing concerns regarding canopy survivability at

future higher altitudes and increased air speeds that would be encountered during military operational deployments. During that test year, more than 60 drops would be deployed over Red Lake DZ, all remote controlled from the RoboTek Mobile Remote Operator Station (MROS) ground station. With excessive wing loads, SCREAMER glide performance was restricted to L/D glide ratios of less than the typical parafoil performance of 3:1, usually 2.0 to 2.4. Sacrificing glide performance for higher forward velocity would prove to be a significant advantage and has been tested successfully in 60 kts winds at altitude.

Single G-12 recovery parachutes were used in conjunction with the 220-ft^2 RAD parafoils supporting up to 2200 lbs while, a pair of G-12s were used above that range and up to 4000 lbs. in conjunction with the 425-ft^2 RAD parafoil. The robust design and construction of RoboTek Engineering's navigation/control actuator package demonstrated practical utility across the full payload weight spectrum, delivering adequate torque for maneuvering the heaviest payloads while only weighing 27 lbs.

As Strong Enterprises moved into the 2003 program development year, the goal was to achieve 6000 lbs. After careful consideration it was decided to push for 8000 lbs in 2003 because there were no practical recovery parachute systems available as standard items in the government stockpile. A 6000 lbs payload would require the use of 4 G-12s and exceeded the capacity of a single G-11. With the understanding that the target program payload weight objective would be 10,000 lbs, which would require a pair of G-11s for recovery, it was decided to immediately strive for 8000 lbs, which coincidentally happened to be the ramp weight restriction on the C-123 aircraft that was being used for testing.

One of the single most significant challenges in the SCREAMER development has been to perfect a smooth symmetrical side-by-side G-11 deployment while loading up the canopies at the same rate and time. With a tendency of one canopy to rob air from the other, one will typically inflate and load up before the other, a problem only occasionally encountered during inflation behind an aircraft with deployment speeds exceeding 150 kts. Over a 4 month period and multiple test sessions, a parallel inflation process was perfected without major modifications and using a novel modified packing procedure and an innovative break-away bridle system. During that test year 66 drops were performed in the 4,000-8,000 lbs weight range using parallel inflation of dual recovery parachutes.

Figure 4
Airborne Guidance Unit

During the 2004 program development year the Strong-RoboTek team performed 47 drops at 8000 lbs from altitudes 10,000-15,000' MSL, also from the C-123 over Red Lake. RoboTek unveiled the first major upgrade to the guidance unit, which included a larger motor and power supply, different processors, a virtually tangle-free control line management scheme, onboard GPS, low profile external antennas, all housed in a nearly indestructible environmentally sealed enclosure. This new generation-2 guidance unit weighed-in at 46 lbs. The beefier motor and gear reduction drive was designed to accommodate heavier control line forces anticipated as the program moved into objective weight ranges of 10,000 lbs. The durability and survivability of the new RoboTek guidance unit was demonstrated in February of 2004 during a deployment malfunction in which the payload separated from the RAD canopy, parting risers and releasing the AGU to freefall from 10,000' MSL. When it was recovered following ground impact, it was operational with a GPS satellite lock and was returned to service after minor repairs. The robust, compact, durable, easily maintained low profile RoboTek AGU was well suited to the SCREAMER program requirements through the years that followed with only minor engineering upgrades. The internal processors and guidance system was readily expandable and built to host autonomous guidance algorithms at the end of CY2003. Thirty-five

Figure 5. 8,000 lbs SCREAMER system lands under a pair of G-11s.
Following a 10K system drop from C-123 aircraft at Red Lake DZ near Kingman, Arizona located in the northwest Mohave Desert.

fully autonomous drops were conducted during the 2004 program year. Mechanically, the new design fit the low drag location requirement, suspended in the risers yet still outside of the structural load path.

Figure 6. Components of 10,000 lbs SCREAMER. *The most significant components that comprise the 10K SCREAMER configuration are illustrated though not in proportional perspective. This modular component approach with no part weighing more than 200 lbs during recovery reduces total clean up and recovery time to less than 15 minutes for 2 experienced riggers.*

Table 1 at the right illustrates the breakdown of the 10K SCREAMER system components with respect to platform weight and actual usable payload weight. The 10,000 lbs total weight refers to gross rigged weight (GRW) at exit from the aircraft. On the drop zone, the heaviest component in the system other than the ECDS platform is a G-11 recovery parachute, which out of the bag weighs 198 lbs. In a typical testing environment, swift clean-up following drops is not a concern, however operationally, if recovery is a concern, complete recovery can be accomplished by two persons in under 15 minutes.

Component	Weight	Remarks
RAD	76 lbs	Canopy & D-bag
AAGU	50 lbs	Including Y-riser
G-11s	560 lbs	2 parachutes
Mantle	40 lbs	Steel tubular frame
Single Point Swivel	25 lbs	For load orientation
Airdrop Equipment	175 lbs	Sling, Clevis', etc.
ECDS Platform	670 lbs	Seabox Type
Potential Payload	8400 lbs	Net payload
Max Rigged Weight	**10000 lbs**	**GRW**

Currently the SCREAMER system is being tested at US Yuma Proving Ground in Arizona from US Air Force aircraft at 10,000 lbs. program objective weight utilizing a 650-ft^2 ram-air drogue and a pair of 100-foot diameter standard Army G-11 recovery parachutes. The 2K SCREAMER system weighing in at approximately 137 lbs., is being tested concurrently using 220-ft^2 RAD's and a SE designed variant of the G-12 recovery parachute, lighter weight, more compact design having the similar flight characteristics. The SCREAMER systems, have logged nearly 150 fully autonomous flights dispatched from distances exceeding 5 nautical miles, altitudes exceeding 18,000 feet MSL and often coming to rest 30 yards or less from the programmed target.

IV. Military Relevance & Linkage to SCREAMER

The US Army Natick Soldier Center (NSC) is teamed with the Joint Forces Command (JFCOM), US Air Force Air Mobility Command (USAF AMC), the US Army Project Manager Force Sustainment and Support (PM-FSS), and under the oversight of the Office of the Secretary of Defense (OSD) Advance Systems and Concepts (AS&C)

office, along with numerous other government agencies and contractors to plan and execute the Joint Precision Airdrop System (JPADS) Advanced Concept Technology Demonstration (ACTD). The JPADS ACTD is integrating a USAF developed laptop-computer-based precision airdrop planning system known as the Joint Precision Airdrop System Mission Planner (JPADS-MP) with the USA Joint Precision Airdrop Systems (JPADS) in the "light" category of weight (2201-10000lbs rigged weights). The integrated system objectives include the ability to airdrop JPADS systems of up to 10,000 lbs rigged weight, from altitudes of up to 25,000-ft MSL, with up to 30kms of offset (in a zero wind condition), and land precisely within 100meters of a preplanned ground impact point. An additional key metric is to have the final system work with the Enhanced Container Delivery System (ECDS) under a gravity drop (ECDS is not extracted), the type V platform, or a 463L pallet (when the payload can be item suspended) and for the entire decelerator/platform system to cost under $60K (in FY04 $s and in quantities of 100).

The purpose of the JPADS ACTD is to meet the requirement of sustaining combat power using high altitude, precision airdrop as a direct and theater delivery method, into a dynamic, dispersed, and unsecured battlespace. This must be done with speed and flexibility to provide an optional capability previously unavailable to the COCOM, and to enable decisive operational superiority. The need for JPADS within the Department of Defense (DoD) is clear from it's ranking within the ACTD reviews. JPADS was ranked within the top 5 ACTD FY04 new starts by all COCOM's, and the Joint Requirements Oversight Council (JROC) for FY04 new start ACTDs ranked it the number 2 priority. An image of the JPADS Concept of Operation (CONOPS) is shown in figure (fig. 2 above).

This JPADS ACTD is integrating the USAF Joint Precision Airdrop System Mission Planning (JPADS-MP) hardware/software (Ref: 1) with the US Army Joint Precision Airdrop System-Light (JPADS-L) airdrop systems (10Klb rigged weight capability). The JPADS-MP provides a mission-planning tool with wireless connectivity to the Army JPADS-L airdrop system(s) on-board the aircraft. This integrated technology allows for rapid pre-flight JPADS programming and in-flight mission, threat, and terrain/environment changes, allowing for immediate reaction by the user to real world variations from plan. It is the intent of the JPADS ACTD to demonstrate and assess systems and technologies that can provide a global delivery system capable of 24-hour fort (CONUS) to fighter (unit/teams) distribution. The JPADS-MP system resides in the cockpit via a high altitude compatible laptop computer that is also loaded with Combat Track II software and connected to the CTII Hardware. (Ref: 3)(Ref:5)

Additionally, a SCREAMER-specific Mission Planner has been developed to provide utility to the SCREAMER systems when used onboard non-JPADS-MP enabled aircraft. This mission planner using S.I.M.P.L.E. software is laptop-based and completely wireless.

V. Military Airdrop and Critical Resupply

Sustainment operations in the theatre and potentially most future conflicts encompass expansive, non-contiguous territories that are time/distance sensitive and subject to the asymmetric threat. Employment of forces calls for significant dispersion, extending units from supply bases and extending the lines of communication. The likelihood that these conditions will be replicated in other operations in which Nation's find themselves combating terrorism is high given the propensity of terrorist elements to disperse utilizing difficult and compartmentalized terrain to mitigate the informational and maneuver overmatches presented to them by US and Allied Nation forces. Theater re-supply operations can be greatly enhanced with the accelerated development and immediate employment of enablers such as JPADS. (Ref:4)

Precision Airdrop Combat Delivery Missions

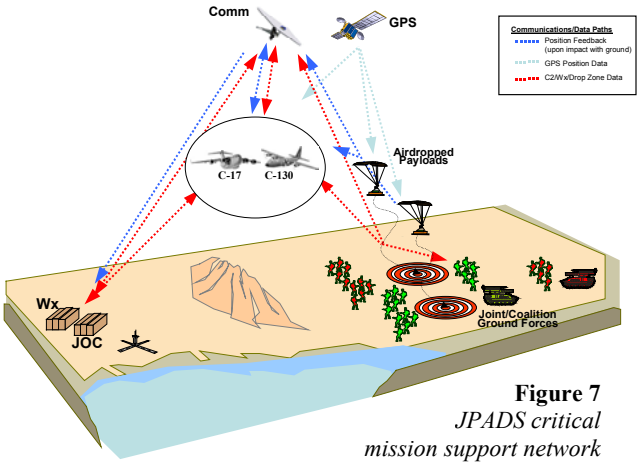


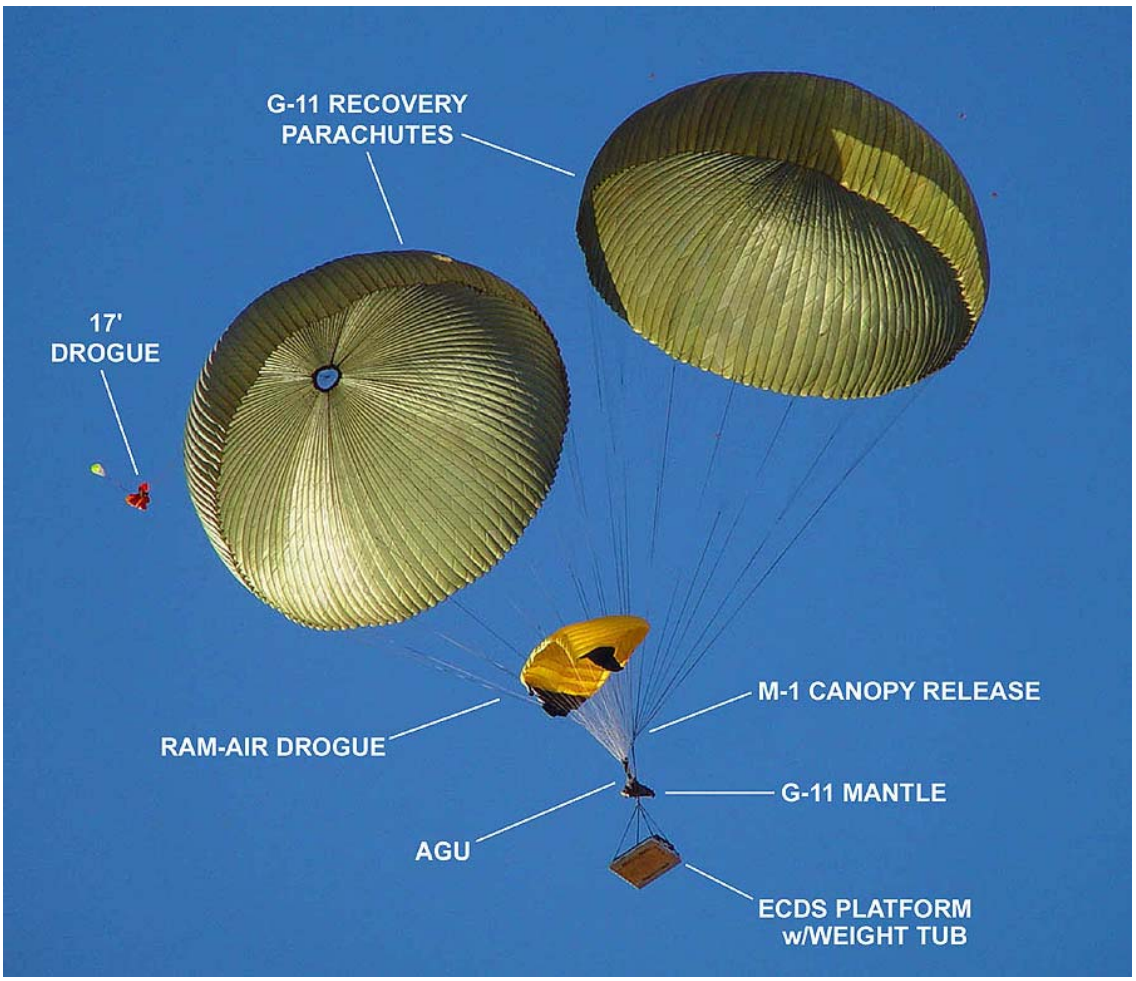
Figure 7
JPADS critical mission support network

Precision airdrop allows aircraft to release

loads at higher altitudes than non-precision airdrop. Non-precision systems significantly affected by winds both at altitudes and near the ground. The ability of precision airdrop systems to control and/or steer in flight allows them to anticipate and counteract the effects of wind on the airdrop system.

VI. System Configuration

The 10K SCREAMER system will be discussed separately from the 2K due to radical differences in their basic configurations. The fundamental components of the 10,000 lbs system are shown below:



A. Guidance, Navigation and Control

The GN&C flight software is native to the AGU itself, hosted on the onboard processor and requires no contact with a ground station during flight. All airdrops are being conducted without relying on the ROS or MROS ground station for control. A telemetry link is maintained throughout test flights, however ground station intervention is only utilized to regain control in the event of a system malfunction.

Figure 8
Airborne Guidance Unit

While SCREAMER is in flight, guidance software is fed information from navigational sensors including GPS and turn rate gyros. Based on these inputs, a computed trajectory toward the first waypoint or the target is resolved. The system is them flown to the target or waypoint with software commanding a series of motor actuator movements to extend or retract the

left and right control lines that manipulate the end three cell trailing edges, left and right in the canopy.

Figure 9. JPADS-MP
JPADS mission planner

Following deployment and RAD canopy having achieved open and full inflation, the AGU commands a four-mode de-spin routine designed to take control of an apparent out of control spiraling load while getting input from onboard rate gyros. Within a maximum of 13 seconds (typically 3-5 seconds) on the 10K system, straight flight will have been attained and the guidance software enters Mode V, navigational mode. SCREAMER will navigate an essentially straight line flight at this stage, with some variation due to influence of upper level winds. When it enters the airspace above the target, it will begin an energy management maneuver circling the target at a preprogrammed radius depending on the altitude at which it enters the target zone. It will continue to circle helically until it reaches a preset altitude, or hard deck, then turn in toward the target. During the mission plan upload prior to flight using JPADS-MP *(fig. 9),* forecast surface winds will have been loaded, and possibly updated during the flight with current data received from wind sondes launched earlier in the sortie. The intensity and heading of surface winds 0-500-ft AGL is now applied in order to resolve an adjusted RP deployment location appropriately offset from the target. Upon reaching a point just before the adjusted coordinates, the software will command the pyrotechnic cutter initiation releasing the pilot and 17' drogue parachute and sequentially both G-11s. The system will then drift under the G-11s in known winds to the target IP. (Ref: 6,7)

B. Main Canopy: Ram-Air Drogue

Figure 10.
Packed SCREAMER RAD

The 10K SCREAMER canopy is a very ruggedly constructed 650-sf parafoil. The design, materials and construction methods employed in it's fabrication are unique and innovative. The SCREAMER ram-air parafoil deploys immediately on exit from the aircraft and sees dramatic opening forces in very turbulent air. The requirement to deal with these destructive forces while supporting 10,000 lbs. has resulted in a level of durability unprecedented among ram-air designs that has rendered consistently reliable openings with minimal inflation incident during deployment. Testing of SCREAMER's ruggedized design construction techniques has been successful in tests exceeding 22 lbs/ft^2 of canopy fabric area. During three years of development testing, more than 140 drops, there was no canopy failures during inflation. Some damage has been noted in recent weeks during higher altitude tests and is being addressed prior to resuming tests.

Figure 11.
Inflated RAD canopy

The 650-ft^2 ram-air main parachute applies a classic 2:1 aspect ratio rectangular planform with a cord dimension of 209 inches and a span of 423 inches. It uses a 19-cell design; every rib is structural with 140 suspension lines. Steering control is readily maintained by using the outer 3 cells It uses staged slider disreefing without the requirement for pyrotechnic devices.

C. The Recovery System

Figure 12
G-11 Recovery Chutes

The SCREAMER parafoil does not and cannot land the payload. The system has no capability to affect a flared landing or to slow forward velocity to the point that a survivable landing is possible. At the time of recovery, this system has an approximate trajectory velocity component of 90-120 mph. For this reason, a pair of G-11 recovery parachutes are initially deployed at 1250 feet AGL above the target and arrest forward velocity and begin a standard vertical ballistic recovery with a descent rate of less than 24 feet/second. It is expected that this deployment will be lowered significantly in the near future. Considerable technical challenges were overcome to devise a method of parallel inflation of the 2 G-11s RPs. At 1250 feet AGL a pyrotechnic line cutter, the only pyro device in the SCREAMER ensemble, will fire releasing the pilot

chute and ring-slot drogue. G-11s deploy and are open and stable at 600-feet AGL. At this point surface winds play a role in driving the package and suspended payload over to the intended point of impact (IP) as predetermined by mission upload of forecast or actual winds at ground level.

Figure 13. Rigged Recovery Mantle
Depicts AGU flanked with G-11s and SCREAMER RAD on top.

The Recovery System, consisting of the G-11 recovery parachutes, 17 foot diameter ring-slot drogue, 3-foot pilot chute, all associated hardware, harnesses, risers and bridles, reside on a 42 inch square tubular steel platform known as the recovery mantle. In RAD drogue flight with the system fully extended during navigation mode, this mantle is suspended below the RAD risers and above the payload sling confluence. It is necessary to locate the Recovery System here to afford the G-11 recovery chutes clean and open air in which to deploy. If placed on the payload, preferred to suspending 600-lbs. in the risers, the opportunity for entanglement in load slings was significant. This location introduced an additional set of challenges including mantle attitude stabilization to assure angular alignment to direction of flight at time of RP deployment and control of platform pitch to minimize drag and ensure on-axis loading of ground canopy releases.

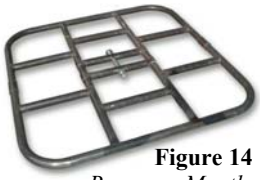


Figure 14
Recovery Mantle

D. Payload and Platform

Payloads with typical suspended weights of 9200 lbs will used with the SCREAMER system. All airdrop hardware associated with the delivery system except the platform itself, accounts for approximately 800 lbs. Payload platform weight will vary. The 4 platforms that have been tested thus far in the 10K JPADS program tests have been the Sea Box ECDS, Capewell ECDS candidate, standard 8-foot Type V and the 463L Logistic platform. The JPADS program has not established a system-specific platform to date, however the Nordisk (Sea Box) is currently favored, but still under consideration since it too is presently in development test & evaluation by Natick PM-FSS.

***Figure 15**. 10K test payload rigged to a 463L Logistics pallet ready for SCREAMER hardware. Suspended wt. ~9200 lbs.*

In the SCREAMER configuration, the payload is either platform suspended or item suspended using 16-foot standard Type-XXVI cargo load slings. The sling confluence terminates at a single point swivel just beneath the Recovery Mantle. The swivel provides load motion decoupling to minimize any possible influence on the RAD parachute and SCREAMER hardware system above. Maintaining platform attitude to the direction of flight is not critical with the SCREAMER system since it typically lands in a vertical ballistic attack with minimal forward velocity. For this reason also the cg of the payload is less of critical than a traditional parafoil landing.

***Figure 16**. Nordisk (Sea Box) ECDS platforms presently under development by Natick PM-FSS Office.*

VII. System Performance & Instrumentation

The RoboTek Gen2 AGU gathers flight dynamics, system performance data and downlinks to the ROS ground station before and during the flights providing there is an active telemetry link. That data has been logged and compiled for all SCREAMER flights since early 2004 and is available to DoD and pertinent contractor personnel for download from the JPADS program website. Included in the figures below is a partial reduction of a representative 10K SCREAMER flight in February 2005 at YPG. Throughout the testing series in Yuma, Arizona, NSC engineers have also provided payload mounted and Recovery Mantle mounted 3-axis accelerometers, rate sensors and GPS, as well as WindPak data from units launched during each sortie which contained JPADS systems. Data from the flight indicated below represents a plan view of the flight track, distance from target, horizontal speed and rudder commands.

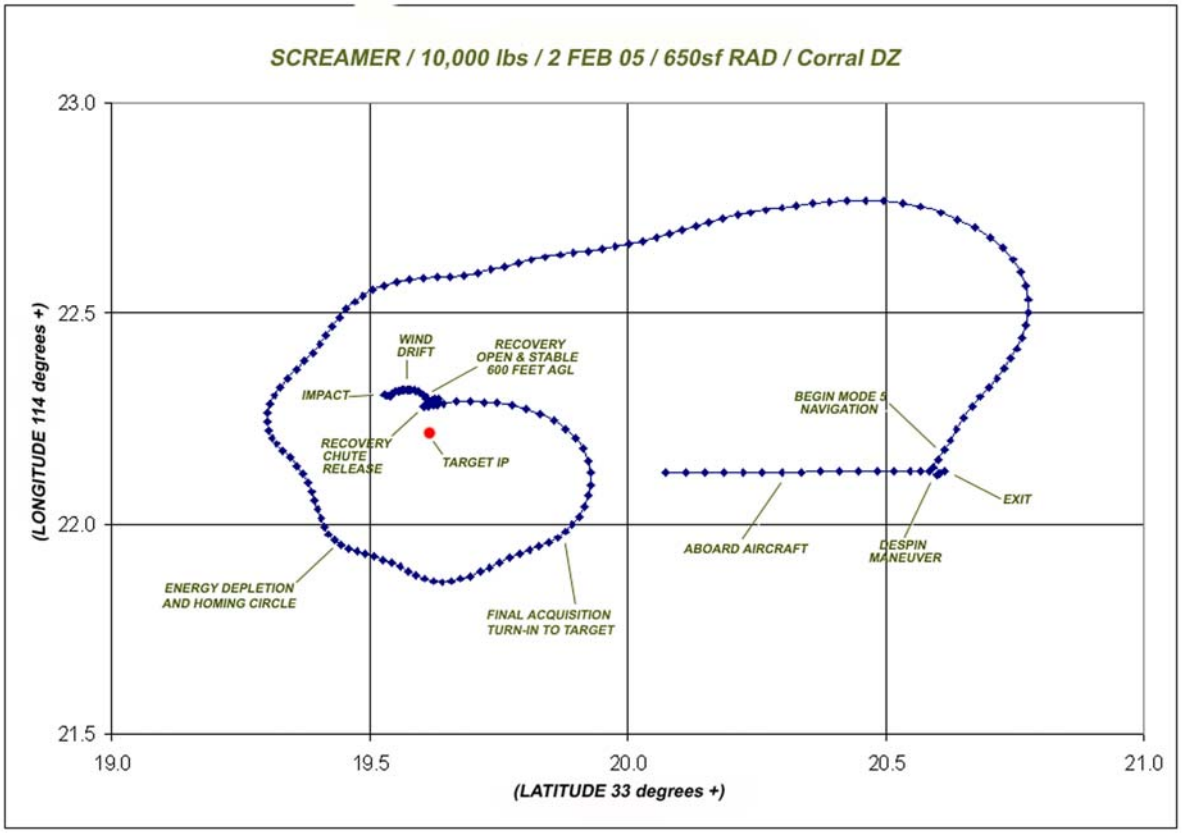


Figure 17. *10K SCREAMER flight track illustrating autonomous modes leading to target homing and recovery phase.*

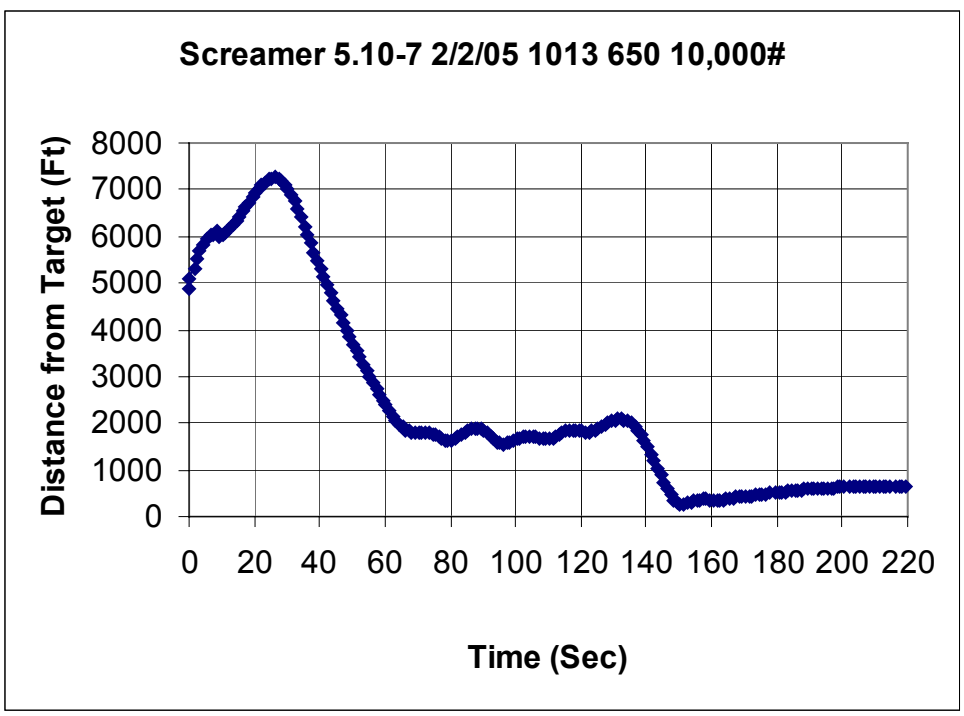


Figure 18. *Same flight as figure 14 illustrating distance to target after exit from aircraft. Please note non-corrected wind drift after recovery parachutes have deployed. Present testing has accounted for surface winds in the 0-500 foot AGL airspace above the programmed target.*

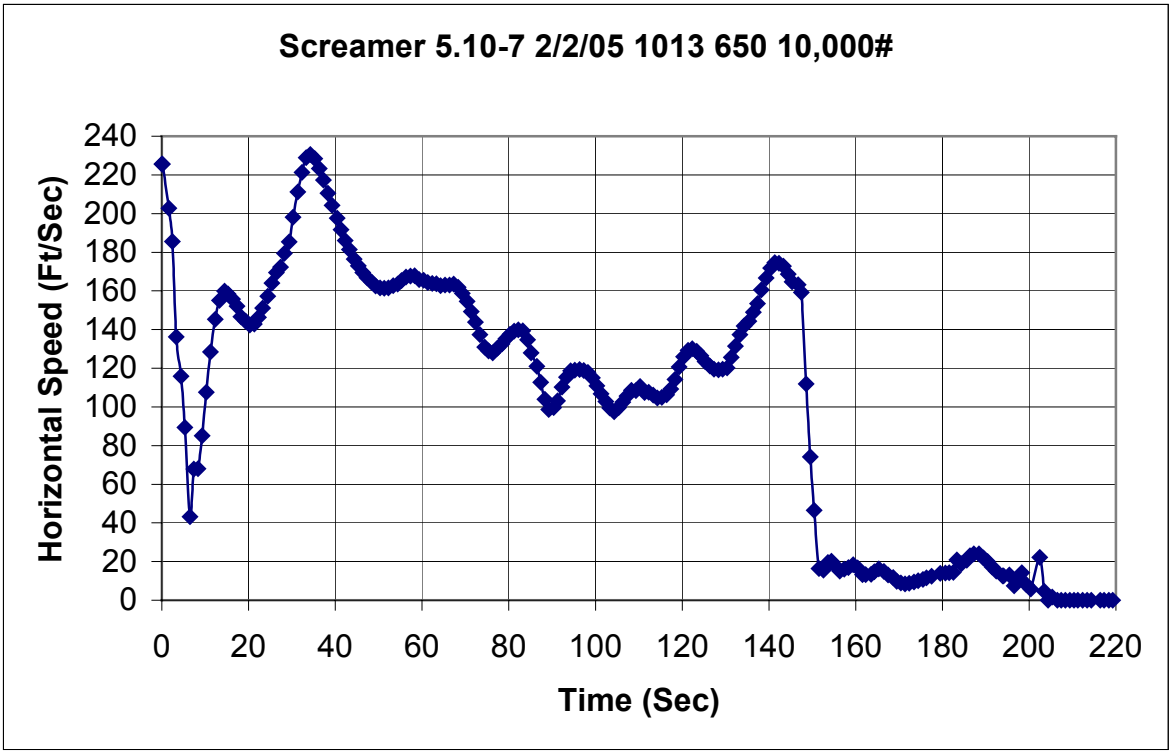


Figure 19. *Horizontal velocity of SCREAMER reaches 157 mph as it crosses through the windline during navigation mode en route to the target. Average ground speed on this flight was 110 mph.*

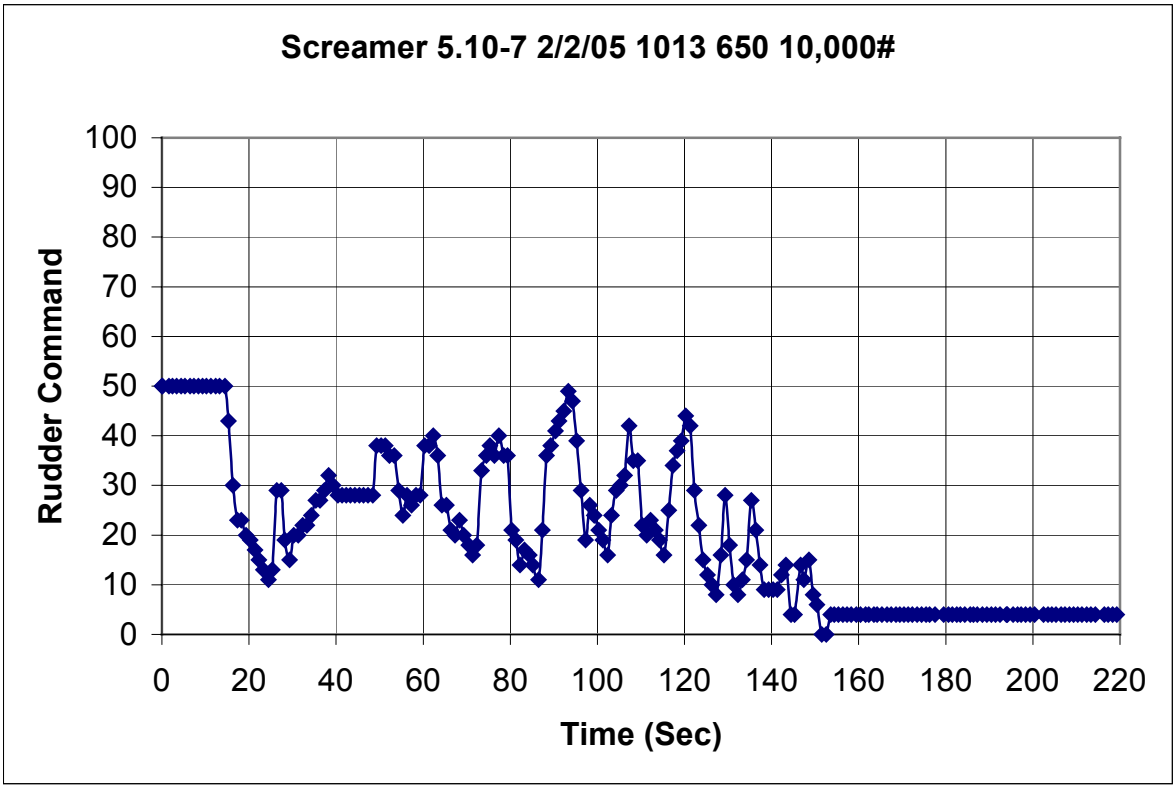


Figure 20. *With RoboTek Engineering optimized gain settings and floating point program deadbands, rudder control toggle actuation is minimized, saving battery capacity, size and AGU weight.*

VIII. The 2000 lbs. SCREAMER System

The evolution of the 10,000 lbs SCREAMER system is based closely on the 2K SCREAMER development. During the FY2004 development year, the two systems began maturing along separate and unrelated paths, although lessons learned during prior SCREAMER development were augmented throughout 10K refinement. The 10K of course, faced significant technical challenges, many of which have been discussed earlier. The Army had no mechanism in place that year to continue investment in the development of the 2K SCREAMER, however Strong Enterprises in alliance with RoboTek Engineering, forged ahead with a new 2K design applying internal, non-government research and development funding. The 2K system was reshaped and underwent a complete redesign, retaining only the AGU common to the 10K System in the new configuration. The 2K SCREAMER development described below is a product of Strong Enterprises and represents insignificant Army investment and does not resemble pre-2004 design concepts included in the G-12 version.

Figure 21. *The 2K SCREAMER during Recovery phase illustrating the Pocket G-12 recovery parachute & RAD*

A. The Army's Vision

The 2K SCREAMER advancement path currently underway within Army funded FY2005 development testing and sponsored primarily through Limited Acquisition Authority by US Joint Forces Command and USAF TRANSCOM, is to prepare SCREAMER for an Operation Utility Assessment. It is anticipated that 2K SCREAMER will undergo rapid fielded during calendar year 2005 to support ongoing DoD operations in theatres abroad. The Army anticipates no changes to the airdrop system architecture currently existing, however several peripheral changes are now underway to complement SCREAMER's operational utility.

Figure 22. Recovery Phase. *SCREAMER deploys drogue and Pocket G-12 at RP initiation as commanded by the RoboTek guidance control software as is crosses through the programmed hard deck above the target IP.*

B. Guidance and Mission Planning

RoboTek Engineering as a subcontractor to Strong Enterprises, has incorporated full wireless programming compatibility to be activated when wireless JPADS-MP becomes functional. Additionally, under an Army contract with PM-FSS Natick, Strong Enterprises and RoboTek have developed a stand-alone, GUI-based wireless Mission Planer, completely independent of JPADS-MP, which allows the 2K SCREAMER full functional utility aboard aircraft that have not been configured for wireless JPADS-MP. Additional complementary enhancements to be included in the 2K system include high fidelity Military GPS immune from hostile jamming and LIDAR forward-looking wind sensors to update SCREAMER's knowledge of wind fields on the DZ during terminal flight phase in preparation for recovery parachute deployment.

C. Performance

The 2K SCREAMER effectiveness during test execution to date has been impressive. Deployments during development testing over the past 18 months have been from 15,000-18,000 feet MSL, at airspeeds of 110-140 KIAS, in upper level winds approaching 60 kts., and with deployment offsets from the target IP of up to 5.2 nautical miles. Recoveries (without knowledge of winds in the target vicinity) have consistently been within a 100 meters of

the intended IP. In the most recent test series at YPG, forecast surface winds based on the USAF weather/winds model have been loaded into SCREAMER's mission plan immediately before the aircraft left the ground. Due to the poor fidelity and inaccuracy of these winds in the lower atmosphere, there was an obvious clustering of payloads on the DZ, offset from the target by the apparent error in forecast winds. The 2K SCREAMER is currently programmed to have the recovery parachute open and stable at 400 feet AGL. Over the next few test series, this altitude will be lowered, leaving SCREAMER less dependent on unreliable wind information and operationally, less vulnerable as a target on non-permissive drop zones in the future.

Pocket G-12 represents one-third the packed

D. The Recovery Parachute

There was one significant change in the 2K SCREAMER configuration during 2004 when the 10K and 2K development efforts split. When Strong Enterprises took over direction of the 2K System they made changes the recovery phase and specifically the new recovery parachute, now designated SE Pocket G-12. Strong abandoned the large and bulky Army standard G-12 recovery parachute in favor of a proprietary SE design that exhibited all the same dynamic performance as the standard G-12 cargo parachute.

The SE Pocket G-12, weighs-in at 37 lbs, one-third the weight of the G-12, has a packed volume of only 2.1 cf., an inflated diameter of 56 feet with 64 gores, low porosity ripstop nylon construction and exhibits a 24fps descent rate when loaded to 2200 lbs. For disreefing it utilizes a common spider-slider. During repetitive development tests since it's introduction in February 2004 as part of the SCREAMER ensemble, it has consistently demonstrated gentle and predictable openings with minimal damage from inflations. The innovative design of this canopy has allowed for a very compact and low-drag system that weighs only 134 lbs.

E. Packing & Rigging the 2K SCREAMER

Figure 24. CDS Payload Rigged. 2K SCREAMER rigging to CDS payloads takes less than 2 minutes.

The overall packed size of the 2K SCREAMER is only 18" x 25" x 18" and weighs 134 lbs. ready for rigging to the payload. Approximate packing time for the system is 1.75 hours for 2 experienced riggers. It takes less than 2 minutes for a single rigger to rig SCREAMER to the payload. The SCREAMER package utilizes a concept of a three-compartment container with the center compartment accommodating the AGU and the two flanking compartments containing the 220 sf. RAD and the Pocket G-12 recovery chute. This configuration presents a minimal presence, low-drag footprint during high-speed navigational mode RAD flight.

Figure 25. *2K SCREAMERs rigged to CDS cargo and awaiting aircraft loading.*

XI. Conclusions

The 2K and 10K SCREAMER systems have made rapid advancements over the past few years through sponsorship from numerous organizations. The systems continue to demonstrate accuracy, economy and survivable precision airdrop of payloads ranging from 500-10,000 lbs. fully rigged weight. The SCREAMER system has been dropped from altitudes (in all weight categories) of just over 18,000-feet MSL. There are current plans to drop them from 25,000-feet MSL over the full weight range are scheduled for CY05.

The SCREAMER system is both, part of a rapid fielding initiative for the Joint Forces Commands Limited Acquisition Authority JPADS program (2K version) and a contender in the JPADS ACTD program (10K version) with nearly complete full wired and wireless linkage to common JPADS-Mission Planner being tested in June 2005.

The SCREAMER system offers a very affordable precision airdrop capability over the widest weight range of any precision airdrop system with a single, common, lightweight AGU. The system has exceptional wind penetration capacity, appropriate offset capability and is currently the quickest delivery precision airdrop system (i.e. from aircraft deployment to ground impact) currently under development.

The 10K SCREAMER system has demonstrated more than 100 fully autonomous drops with 35% of those landing within 100 meters of the designated target. Strong Enterprises has rigidly adhered to the system cost price-line guidance that was laid down by the Army at the outset of the ACTD. The 10K SCREAMER has a minimal consumables cycle cost of just over $100 per drop.

At the time of this submission, the 10K SCREAMER system is one of two 10K JPADS-L decelerator systems being developed under the JPADS ACTD with a "user prioritization" decision scheduled during the summer of CY05 to determine which system will continue throughout the JPADS ACTD program. The 2K system is being evaluated at this time for potential rapid fielding to current operations by the end of CY05.

Acknowledgements

The authors of this paper and the SCREAMER team made up of the US Army Research, Development and Engineering Command (RDECOM), Natick Soldier Center, Strong Enterprises and RoboTek Engineering would like to thank the following sponsors who have helped make the program such a success to date. These organizations include (in addition to the Natick Soldier Center as primary sponsor), the Deputy Under Secretary of Defense for Advanced Concept and Systems (DUSD AS&C), the US Joint Forces Command (JFCOM), the US Air Force Air Mobility Command (with many other USAF organizations supporting them), US Army Product Manager Force Sustainment Support (PM-FSS), Mr. Jim Blumenthal (C-123K commercial pilot in Kingman, Arizona), the US Army Yuma Proving Ground, and US Transportation Command (TRANSCOM). SCREAMER's success has been a team effort and matured more rapidly due to all of the above organizations support.

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The following authors' works are referenced in this document. As of this date, some references have not been published but have been submitted to the AIAA decelerator conference for inclusion in May 2005.

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