Design, Development & Flight Testing Of The U.S. Army 4200 ft² Parafoil Recovery System

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Abstract

The purpose of this paper is to describe the design, development and flight-testing of the U.S. Army 4200 ft² parafoil recovery system built under NASA Contract NAS 9-00076. The 4200 ft² parafoil described herein was a potential candidate to fulfill the U.S. Army requirement for a 10,000 lb useable payload precision guided recovery system. Design heritage as well as specific features, like lower surface inlets, confluence fitting, upper surface energy modulator design, deployment bag design and 60 ft diameter Ringslot drogue will be discussed. Initial flight test results, ground testing of various components to verify design margin and configuration changes will also be discussed. The 4200 ft² parafoil recovery system completed three flight tests during 2003 at payload weights of over 15,000 lbs.

I. Nomenclature

PRS	Parafoil Recovery System
ARS	Advanced Recovery System
GPADS	Guided Parafoil Aerial Delivery System
YPG	Yuma Proving Ground, Yuma, AZ
PGNC	Parafoil Guidance Navigation Control
ESA	European Space Agency
LE	Leading Edge
TE	Trailing Edge
fps	foot per second
ISS	International Space Station
PGNC	Parafoil Guidance, Navigation and Control
kft	1000 ft
lb_m	pound mass
oz/yd²	ounce per square yard
EFTC	Extraction Force Transfer Coupling
MSL	Mean Sea Level
AGL	Above Ground Level
LVAD	Low Velocity Air Drop
LCWW	Low Cost War Wing
JSC	Johnson Space Center, Houston, TX
GFE	Government Furnished Equipment
ft	feet
lb_f	pound force
CdA_o	full open drag area
CRV	Crew Return Vehicle
g's	acceleration due to gravity
KIAS	knots indicated airspeed
TS	tensile strength
D_0	Nominal Diameter

II. Introduction

Since 1989, Pioneer Aerospace Corporation has been developing and flight testing large parafoil systems, originally for the NASA Marshall Flight Test Center for the ARS Program, followed by the U.S. Army for the GPADS Program, for NASA JSC for the X-38 Program and more recently for the U.S. Army for the 30,000 lbs Parafoil Recovery System Program. These parafoils, when combined with guidance and control systems, have demonstrated the feasibility of final descent with controlled flight, and accurate landings of heavy cargo loads at weights up to 36,000 lbs. Parafoils have been flown in the sizes of 750,

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3600, 4200, 5500, 7350 and 7,500 ft^2. Recent progress related to the 4200 ft^2 parafoil made for the U.S. Army under the NASA X-38 contract is described herein.

III. NASA X-38 & U.S. Army Natick Program Description

The NASA X-38 spacecraft was the prototype for the ISS Crew Return Vehicle. The 25,000 lb CRV was to have been able to reenter the atmosphere with a crew of up to seven ISS astronauts and would have used a staged parachute system for stabilization, deceleration, terminal descent and landing. The X-38/CRV PRS consisted of a mortar-deployed 9-ft diameter pilot parachute, a 100-ft diameter drogue parachute, and a 7500 ft^2 parafoil. The CRV was to incorporate an onboard PNGC System that would close the guidance loop around signals from GPS satellites. The ESA and NASA developed PGNC commanded parafoil flight maneuvers and controlled the parafoil to a soft, into-the-wind, flared landing. Bennett[1] and Stein[2] provide additional details on the X-38 PRS program. Due to NASA budget constraints, the X-38 and CRV programs were terminated during 2003.

In an effort to maintain the core X-38 team and exploit the advanced development of large parafoil technology for Department of Defense applications, NASA and the U.S. Army funded Pioneer to build and test the 4200 ft^2 parafoil for an application to deliver 10,000 lbs of usable cargo. The 4200 ft^2 parafoil design used the successful X-38 7,500 ft^2 parafoil as its baseline with a main focus to reduce the canopy costs to bring it more in line with the U.S. Army needs. The target U.S. Army cost goal for the program was $3 to $6 per pound delivered, or $30,000 lb to $60,000 for a 10,000 lb payload.

IV. Parafoil Recovery System Description

The PRS was comprised of a 60 ft Ringslot drogue, a 4200 ft^2 parafoil, a pyrotechnic event sequencer and a NASA guidance system. A standard 28 ft diameter extraction chute was used to extract the payload from the cargo aircraft.

A. Recovery System Design Requirements

At the PRS Preliminary Design Review on 10/2/02, the following objective design requirements were presented:

- Max. weight for usable cargo = 10000 lbs.
- Nominal drogue deployment altitude of 25kft (MSL) w/ ability to handle 35kft (MSL) @ 200 KIAS
- Max. Aircraft speed = 130 – 150 KIAS w/ ability to handle 200 KIAS @ 35kft (MSL)
- Minimize altitude loss from drogue deployment to guided flight
- Safety factor: 1.5 w/ standard derating factors
- Total system cost target: $3/lb to $6/lb delivered
- Use GFE (YPG & NASA) equipment were possible to minimize expense
- Minimum cutters per reefing event: 2
- Maximum payload deployment shock requirement: 3g's (per MIL-STD-814D)
- Parachute storage temperature requirements: assume controlled environment
- Maximum storage time: 3 years
- Use derivative of current X-38 PRS design for new U.S. Army PRS
- Nominal vertical velocity at landing: 20 fps or less (no flare)
- Landing accuracy: 100 meters
- Initial test article: 12 ft weight tub rigged on 20 ft standard airdrop platform
- Minimize airborne debris as much as possible

B. Drogue Parachute

The drogue parachute functioned to provide the initial deceleration and stabilization of the payload, programmed the conditions for parafoil initial inflation, and extracted the parafoil from the top of the payload. The drogue parachute was a 60 ft diameter, 48 gore, nylon Ringslot design and used three reefed stages for inflation load management. The full open drag area of the 60 ft diameter drogue was approximately 1640 ft^2, corresponding to a drag coefficient of 0.58. Terminal velocity under the drogue with a 15,000 lb_m payload was approximately 110 fps. Maximum drogue parachute loads occurred at full open inflation with peak loads typically approaching 3 g's. With design factors of approximately 2.5, the drogue had a zero safety margin load of 50,000 lb_f.

The Ringslot panels were constructed of 2.25 oz/yd^2 nylon fabric. The canopy radials were made of 1500 lb_f TS nylon ribbons, while the verticals were made from 500 lb_f TS nylon tape. Skirt band was constructed of 3000 lb_f TS nylon ribbon and the vent band was made from 9000 lb_f TS nylon web.

In conjunction with 1.0D_0 length nylon suspension lines, the drogue parachute used one each 60 ft nylon, 3 loop riser extension to set the desired trailing distance. The drogue canopy and riser extension were packed into a 16 inch high by 16 inch wide by 40 inch long deployment bag that was located near the rear of the payload. The total drogue parachute pack weighed 250 lb_m. The drogue riser extension was connected to a G-11 clevis and connected to the airdrop platform using standard, 4-loop, nylon slings. Figure 1 shows deployment images of the 60 ft drogue during a typical LVAD test at YPG.

Figure 1 – 60 ft Drogue During LCWW-2 Drop Test

At the drogue release event the drogue main slings were severed, leaving only the parafoil deployment sling connected to the parafoil deployment bag. The freefalling payload would then begin the parafoil deployment process.

C. Parafoil Configuration

The 4200 ft^2 parafoil provided the final payload deceleration/guidance and means for soft landing. The parafoil had a lower surface chord length of 39.9 ft and a span of 105.5 ft for an aspect ratio of 2.64. The wing section was a modified Clark-Y airfoil with a maximum thickness of 14.8% and an inlet cut angle of 43°. The parafoil was designed for a wing loading of 3.6 lb/ft^2, which corresponds to a parafoil flying weight of just over 15,000 lbs to achieve the desired capability for delivering 10,000 lbs of usable cargo.

The parafoil had 27 cells and used four stages of Pioneer-patented spanwise reefing for inflation load management. Reefed cells were laced from the TE to the LE along the lower surface and unlaced by the firing of specific time delay cutters. The first deployed stage consisted of 9 cells, two at each tip plus two inboard single cells and the three center cells. The second and third stages consisted of 5 cells each. The fourth and fifth stages consisted of 4 cells each. Typical reefing cutter time delays were 6, 12, 16 and 24 seconds and armed at the parafoil line stretch event. Maximum inflation loads for the parafoil occurred in first stage and consistently approached 3 g's. Inflation loads for the later stages ranged from 2.75 to 1.5 g's. With design factors of approximately 2.5, the parafoil has a zero safety margin load of 58,000 lb_f.

1. Upper Surface Details

The shaped, upper surface panels of all cells were made from Aeromax™, a silicone-coated nylon cloth, having a tensile strength of 90 lb_f/in. The upper surface near the trailing edge of cells 1, 2, 13, 14, 15, 26 and 27 were reinforced with 225 lb_f/in nylon cloth , since this region was prone to damage. 4,000 lb_f TS nylon tape spanwise reinforcements/ripstops were evenly spaced across the upper surface and designed to carry spanwise loads in the event a tear occurred between the ripstops. In addition, all 1st stage upper surfaces were fitted with chordwise ripstops to limit deployment related damage, especially on wing-tip cells. See Figure 2 for images of canopy's upper surface.

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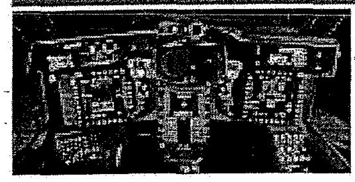

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