Purpose: This paper describes *NCE's* parafoil flight vehicle technology and the implications to military operations. This information is intended to inform US and allied visionaries who seek high value solutions to basic and special military capabilities related to the third dimension of flight. Distribution is unrestricted.

Background: The defense department has two basic approaches to sustained flight; fixed and rotary wing aircraft. There are also lighter-than-air systems that are tethered, free-floating, or powered that have a long history with niche periods of operational utility. What has not been explored, yet has great potential are parafoil winged flight vehicles.

What we've seen in the DoD are unpowered parafoil wing systems better known as Aerodynamic Deceleration Systems (ADS). For decades they've been used for military parachutists to free-fall precisely into drop zones. More recently, parafoils deliver a wide variety of payload weights(2k-60k lbs) via the JPADS system. In these applications alone, a few unique and powerful qualities stand out. Parafoils pack into very small volumes, are versatile, scalable, and fly well. Perhaps most discerning though is that they are low-cost and lightweight. In fact, as the Dod's aircraft have seen the steady increases in cost with most exotic materials and designs, in many potential applications a powered parafoil system could radically disrupt that trend.

Figure 2. JPADS Aerial Delivery

Figure 1 Night Precision Freefall

Figure 4 Cargo aircraft provide worldwide delivery in under 24 hours

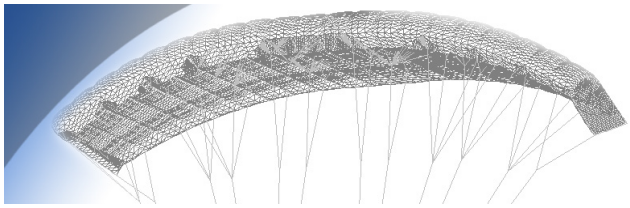

Figure 5 Analytical modeling of advanced parafoil wings

Figure 3 C-17 high-altitude air drop CONOP enables world-wide deployment directly/near station orbit.

Powered Parafoil Aircraft: Adding propulsion to the parafoil hit stride in the 90s with sport flight enthusiasts adding small motors with pusher propellers to a simple wheeled carriage. Along with the ease of operations and ability to park the "airplane" in the shed, the cost was probably the greatest driver for the Powered Parachute industry that peaked at the turn of the century with over 30 manufacturers. As the wings improved for gliding, engines were also added to backpack propulsion for the lightest man-portable paramotors. At the same time, *NCE* built and demonstrated a 1-ton aircraft that could also go off-road like no other airplane before.

Classically, fixed-wing aircraft evolved to go faster and higher more efficiently. This led to lighter structures and cleaner aerodynamic designs optimized for the desired payload and mission. Consequently, if there's a new mission, you often need a new aircraft. Powered parafoil aircraft on the other hand are easily scaled and re-winged for the desired performance and payloads within their unique flight envelop.

Figure 6 Paramotor Hobbyist Record paraflight to 27k highlights performance, value, and potential

Figure 7 Autonomous navigation and landing development flights in 2015

Parafoil Flight Envelope and Performance: Parafoil wings have been demonstrated out to 100mph, but typically fly at speeds from 25-50mph. The typical altitudes of operations are below 20,000feet; however, *NCE* has supported parafoil flight operations over 100,000 feet. In general, parafoils fly across an extremely wide altitude envelope and avoid compressibility effects since they fly so slowly. Their slow flight speed also makes them ideal for station-keeping and poor for long-range higher speed transportation.

Parafoil flight performance is a function of wing lift-to-drag ratio, wing-loading, and the propulsion system. In general, wings are easily modified to accommodate flight operating altitudes, payload, and mission needs. Compared to typical aircraft characteristics powered parafoil aircraft have radically different qualities that enable long-endurance station keeping and mission versatility that challenges current mission optimized fixed-wing systems.

Because of the extremely light-weight and strong tensile parafoil wing, the dry vehicle typically has double the payload ratio of even the most optimized fixed-wing aircraft. 50% payload ratios are typical. Similarly, the fuel fraction is easily driven to levels unheard of for fixed wing aircraft. A 70% fuel fraction is possible with the 50% payload ration configuration.

Joint Need/Application Options: Powered Parafoil systems have numerous offensive and defensive applications. They could provide worldwide gap-filler high-ground sensor or comm/nav augmentation. At lower altitudes they could provide supply and personnel transportation. Due to their low cost and unique qualities they could also provide access to even the most stressing A2AD environments. With a EW payload they could prove a valuable low-cost decoy system that mimic complex maneuver forces.

Summary Parafoil vs Fixed-wing Performance

Pro/Con	Quality/ Feature	Rationale
+	Payload & Fuel Fraction	W/o the significant wing structure and an optimized on-station configuration, parafoils turn payload and fuel fraction upside down.
+	Slow Speed	Flight speed only slightly above wind speed aloft reduces work required for Station keeping. Uncompressible flow/low speed aero analysis except for prop.
-	Cruise Performance	Ability to relocate or transit, compensated by C-17 delivery to or near station. Like sailing or flying anything, the winds and environment must be planned for and managed
+	Packaged Size	Transformer-like air vehicle can fit into cargo aircraft for delivery to station. Easy to handle and transport on the ground
+	Parafoil Wing	Easily sized or changed for optimum weight/performance and evolution of wing technology. Unproven at altitude (see risks)
+	Lighter Wing Structure	Parafoil wings weight are a fraction that of a fixed wing. In tension they are very robust and strong.
+	Air Deliverable Location[3]	Deployability: Cargo aircraft airdrop allows for all vehicle fuel to be dedicated to on-station endurance. No airfield/runway requirements
	Location: Anywhere/Anytime	Rapid World-Wide stationing
	Location: Hi Altitude Start	High Altitude delivery avoids climb and transit to even high-altitude stations. Engine/propulsion optimized for operations
	Location: Clear/Calm Air	Flexible delivery allows for clear/calm air deployment and avoidance of adverse weather
+	Recoverable Anywhere	Redeployment: Precision Glide recovery to small fields/roads/water then transport to regeneration airfield very flexible. Low/bingo landing weight, assures easy handling
-	Wing Performance	Parafoils have more drag than fixed wings and a lower Lift/Drag potential due to required anhedral and suspension lines. However, in just the past 5-year L/D performance has doubled and potential for greater improvement is high.
-	Wing Handling & Control	Parafoils are susceptible to turbulence and cant handle bending or compression loads so tension on the wing is always required. High Aspect Ratio wings are even more vulnerable to this problem. Stratospheric ops and wing stability focus of this program mitigates this risk.
+	Survivability - Signature	LO signature in broadest spectra possible. Vulnerable areas are minimal. Back up chute for safe recovery a low cost option
+	Survivability – Exchange Ratio	Platform costs with EW decoy payload could easily fall to a fraction the cost of threat weapons. The cost exchange ratio is an area the US has typically avoided, but should consider.

Figure 8 Parafoil "kite" used for extending ship's ISR look. If powered could provide untethered support and defensive capabilities.