Powered paragliders in biodiversity exploration

Uso de paramotores para explorar la biodiversidad

Mark E. Olson

Instituto de Biología, Universidad Nacional Autónoma de México, Apartado postal 70-367, 04510 México, D. F. México
Correspondent: molson@ibiologia.unam.mx

Abstract. Transportation technology is key to biodiversity exploration, and innovations often provide new access to biological questions. Powered paragliders are very small powered aircraft developed for recreational use that have great potential for use by scientists. I provide an introduction to these aircraft based on my experience studying tree crowns in tropical Mexico, with the aim of giving sufficient information that the suitability of powered paragliders for a given research project can be evaluated. The aircraft consists of a parachute-like fabric wing from which the pilot hangs (the paraglider), and a small gasoline motor behind the pilot. The benefits of these aircraft include portability, low cost, slow flying speed and the consequent ability to fly relatively safely at low altitudes. Because takeoff and landing are accomplished by running, paramotors can be operated from fields that are too rough for airplanes. Because they are so small and the wing has no rigid parts, they are vulnerable to turbulence and must be flown in very benign weather. Likewise, they are heavy and awkward when on the ground. As a result, they are as excellent observation platforms in localized areas, but inadvisable for transport of people or cargo.

Key words: aerial photography, aerial surveys, aviation, exploration technology, field work, flight, paramotor, transportation.

Resumen. Muchas veces las innovaciones tecnológicas brindan respuestas nuevas a problemas biológicos. Parte clave en la exploración de la biodiversidad es la tecnología del transporte. Los planeadores son aeronaves muy pequeñas desarrolladas con fines deportivos que tienen gran potencial de uso por parte de los biólogos. Con el fin de brindar suficiente información que posibilite evaluar la conveniencia de su empleo para determinados fines biológicos, aquí se presenta una introducción a estas aeronaves basada en mi experiencia al estudiar las copas de los árboles en el trópico mexicano. La aeronave consiste de una ala de tela que se parece a un paracaídas (parapente), de la cual cuelga el piloto, que lleva un pequeño motor de gasolina en la espalda. Estas aeronaves incluyen varias ventajas, son fáciles de transportar, tienen bajo costo, baja velocidad y la consecuente posibilidad de volar a baja altura de manera relativamente segura. El despegue y el aterrizaje se realizan con los pies; por lo tanto, es posible utilizar campos que serían excesivamente accidentados para una avioneta. No obstante, su ligereza y la ausencia de un ala rígida los hacen vulnerables a la turbulencia, por lo que es necesario que las operaciones se lleven a cabo únicamente cuando las condiciones atmosféricas son benignas; asimismo, son notablemente pesados cuando se está en tierra. Gracias a su combinación particular de características, resultan excelentes plataformas de observación aérea para estudiar pequeñas zonas, pero no se prestan para transporte de personas o de carga.

Palabras clave: fotografía aérea, inventarios aéreos, aviación, tecnología exploratoria, trabajo de campo, vuelo, paramotores, transportación.

Introduction

Studying a map of virtually any part of the world reveals the enormity of the effort to understand the distribution of biological diversity. Inaccessible peaks, rugged canyons and seemingly endless flats vastly outnumber the biologists available to explore them. In a time when striking novelties continue to come to light (e.g. Jenkins et al. 2004; Jones et al. 2005; Klass et al. 2002; Turner, 1996), it is clear that countless remarkable discoveries await both in remote and well-studied reaches of the world. As a result, biologists

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have enthusiastically adopted technologies that promise new access to biodiversity (e.g. Arnold, 1967; Steyermark, 1974).

This paper reports my experience as a biologist with a paramotor or powered paraglider, the smallest, lightest, and most portable of all powered aircraft. These aircraft have become available only recently, with the development of special fabrics and the adaptation of lightweight motors. Many biological enterprises can benefit from an aerial view, but conventional aircraft such as airplanes and helicopters have many drawbacks, including cost and the difficulty of transporting them to the field. For some applications, powered paragliders may provide an effective and economical alternative. The objective of this paper is to provide an introduction to this unfamiliar type of aircraft, and to comment on biological applications for which it can or cannot be useful based on my experience studying tree crowns in tropical Mexican forests. While not a manual for operating a paramotor, I aim to give sufficiently detailed information that biologists can decide if a paramotor is appropriate for a given application.

My use of a powered paraglider is the result of field trips in northeast Africa in 1997-98 in which I hired single-engine airplanes to reach remote localities efficiently and safely. After many hours in the air at low altitude, I realized that the flat-topped acacias so abundant in African forests, despite appearing similar in habit when viewed from the ground, display an amazing diversity of crown arrangements when seen from the air (Fig. 1). How to observe the same tree from the ground and from the air on the same day? Helicopters are far too expensive, and airplanes are in general too fast and too difficult to work with efficiently in remote areas. For my need to have various views of large trees, the ability to take to the air, but not very high or very fast, is ideal.

In the discussion that follows, my intention is to provide considerations for biologists, not sportsmen practicing daily. There are many feats that highly skilled sportsmen can accomplish, such as landing on a tennis court-sized clearing in a forest, that are beyond the reach of most biologists, who must use the paramotor as a tool in their research and cannot dedicate entire days to maximizing their piloting proficiency. Instead, I emphasize potential applications that are entirely feasible given a reasonable level of piloting skill that could be maintained by weekly flights. My experience also suggests that the quality of paramotor instructors varies greatly. There is no certification process necessary and in most countries, a paramotor can be purchased and flown with no legal oversight at all. Therefore, I also record here some important insights gained in the field.

A paramotor is made up of two components, the paraglider and the motor. A paraglider is an inflatable fabric wing with no rigid parts. Inflation is achieved through ram air filling the open leading edge of the wing (Fig. 2A, B). The wing is made of very light, strong nylon fabric that is treated with a coating to make it impermeable and thus to permit the negative pressure on the upper surface of the wing to generate lift (Babinsky, 1999). The wings are usually narrowly elliptic, with 20-50 vertically-oriented fabric ribs binding the upper part of the wing to the lower and maintaining the correct airfoil shape. Somewhat like a parachute, a series of very strong, thin lines run from all over the lower surface of the wing to two webbing loops called risers, to which the pilot harness is attached (Fig. 2C, D). The harness hangs from the risers when in flight, and the entire weight of the pilot and the engine is supported by the wing. In flight, the pilot generally sits strapped into a flexible seat. Steering is by means of two control lines that connect via cascades of lines to the entire trailing edge of the wing (in the pilot's hands in Fig. 2C). Pulling on one control spoils the lift on that side of the wing slightly, and the paraglider turns in that direction. Sustained pulling very hard on both control lines will spoil

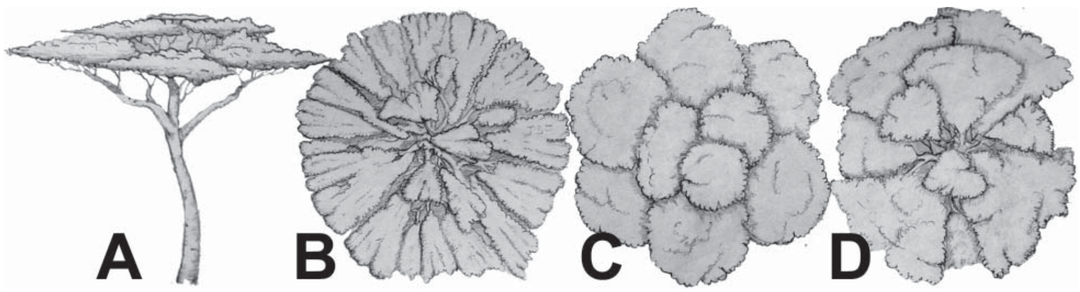

Figure 1. Crowns of flat topped *Acacia* trees from northeast Africa. A. From the ground, most species have a similar appearance, with a tall single trunk and a notably flattened crown. B-D. Aerial views. Despite their apparent similarity from the ground, as seen from above, some flat-topped *Acacia* have long, finger-like foliage masses (B), rounded, tufted masses (C), or wedge-shaped tables of foliage (D).

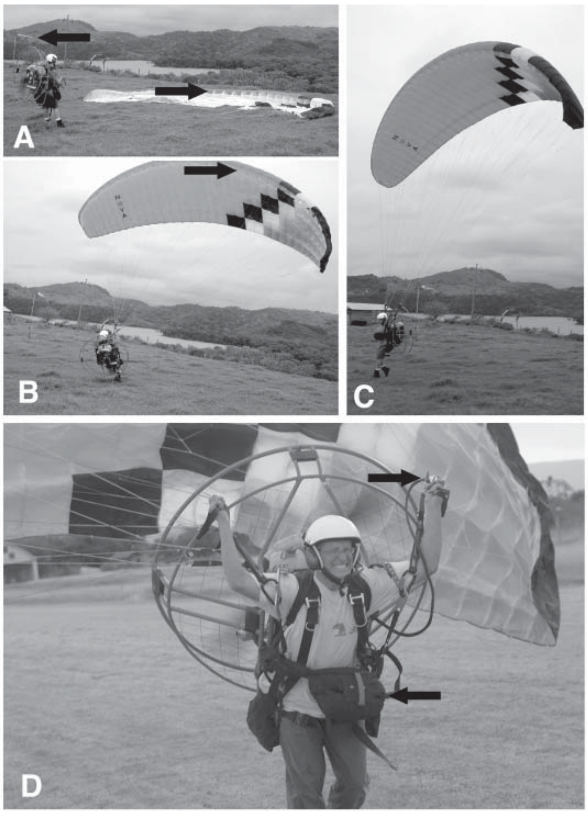

Figure 2. Takeoff. A-C. A reverse inflation. A. Pre-takeoff engine warmup. Note backward lean to resist thrust of motor. The wing is oriented more or less perpendicularly to the wind, indicated by windsock (left arrow). The right arrow shows the leading edge openings in the wing. B. Lofting the wing. With several determined steps backwards, the leading edge of the wing is lifted, allowing the wind to inflate it. Much like flying an enormous kite, continued backward movement brings the wing directly overhead. Note the deep backward lean required to resist the considerable pull exerted by the wind on the great surface area of the wing. The arrow shows the leading edge openings on the now-inflated wing. Note the crossed risers. C. Once the wing is overhead, it is a simple matter to turn around, apply full power, and climb away from the ground. This image was taken at the moment of liftoff, with the pilot's feet barely skimming the ground. D. Forward inflation. This takeoff, at high elevation (1600m) on a hot day with little wind, required much more exertion than the reverse inflation pictured above. In this case, the pilot runs until the wing is lofted and takeoff speed is attained. In this image from Morelos State, the takeoff required more than 50 meters. The upper arrow indicates the throttle, whereas the lower arrow shows the reserve parachute, in this case, carried in a pouch on the stomach. Photos 2A-C by John Pearson; 2D by Jim Webb.

the lift to the entire wing, causing it to stall. The motor is usually a single-cylinder two-stroke gasoline engine providing thrust via a small propeller. The motor and propeller are surrounded by a cage that prevents the lines from tangling in the propeller during takeoff and landing and prevent elbows, hands, and feet from contacting the propeller during flight (Fig. 2D).

One of the most attractive features of powered paragliders for biological fieldwork is their portability. We regularly take to the field a powered paraglider and a large amount of field equipment in a standard bed pickup truck. The wing is simply folded up and carried in a large stuff sack. If space is not available, the propeller can be unbolted from the engine and the cage disassembled. Disassembled, the motor and associated parts can be transported even in a small passenger car and even taken as luggage on airliners. National Geographic photographer George Steinmetz has taken his powered paraglider to many parts of the world in this way.

For takeoff, two main techniques are used to inflate the wing, depending on the amount of wind available. At moderate wind speeds, a "reverse" inflation may be used. A reverse inflation is performed with the pilot facing the wing, and allowing the wind to inflate the wing and loft it over his under constant visual control. The risers are crossed in such a way that, once the wing is lofted, the pilot can turn around, add thrust, and take off (Figs. 2A-C). A forward inflation is used in conditions of low wind, and requires the pilot to take off facing forward, making it difficult to monitor the position of the wing visually (Fig. 2D). Paraglider enthusiasts usually take off from sites that have been often used by other sportsmen. Biologists do not usually have this luxury and must therefore be prepared to prepare the field themselves for takeoff. A certain space must be available in which the wing can be laid out without snagging. The area of extensive pasture in Figs. A-C would be ideal were it not for the spiny *Mimosa* and a particularly annoying species of *Randia* that are common at the site. These must be removed by hand before the wing can be laid out. The entire takeoff stretch and the landing site should be walked several times to detect dangerous irregularities or holes. A helpful tool is a wind indicator; clipper poles for plant collecting can double as a windsock holder (Fig. 2A). A further consideration is that an area free of hazards to the right must be available, because, due to the torque effect of the spinning propeller, the pilot inevitably makes a spiralling ascent on takeoff.

Landing is a relatively simple matter, and does not require an airstrip. One of the main advantages of powered paragliders is that fields that are much more irregular and smaller than those required for small airplanes can be used for landing. Because the landing gear of a powered paraglider are the pilot's feet, even very grassy, sandy or hummocky terrain can be used safely. The simplest landing procedure involves simply shutting off the engine. A particularly important consideration for biologists

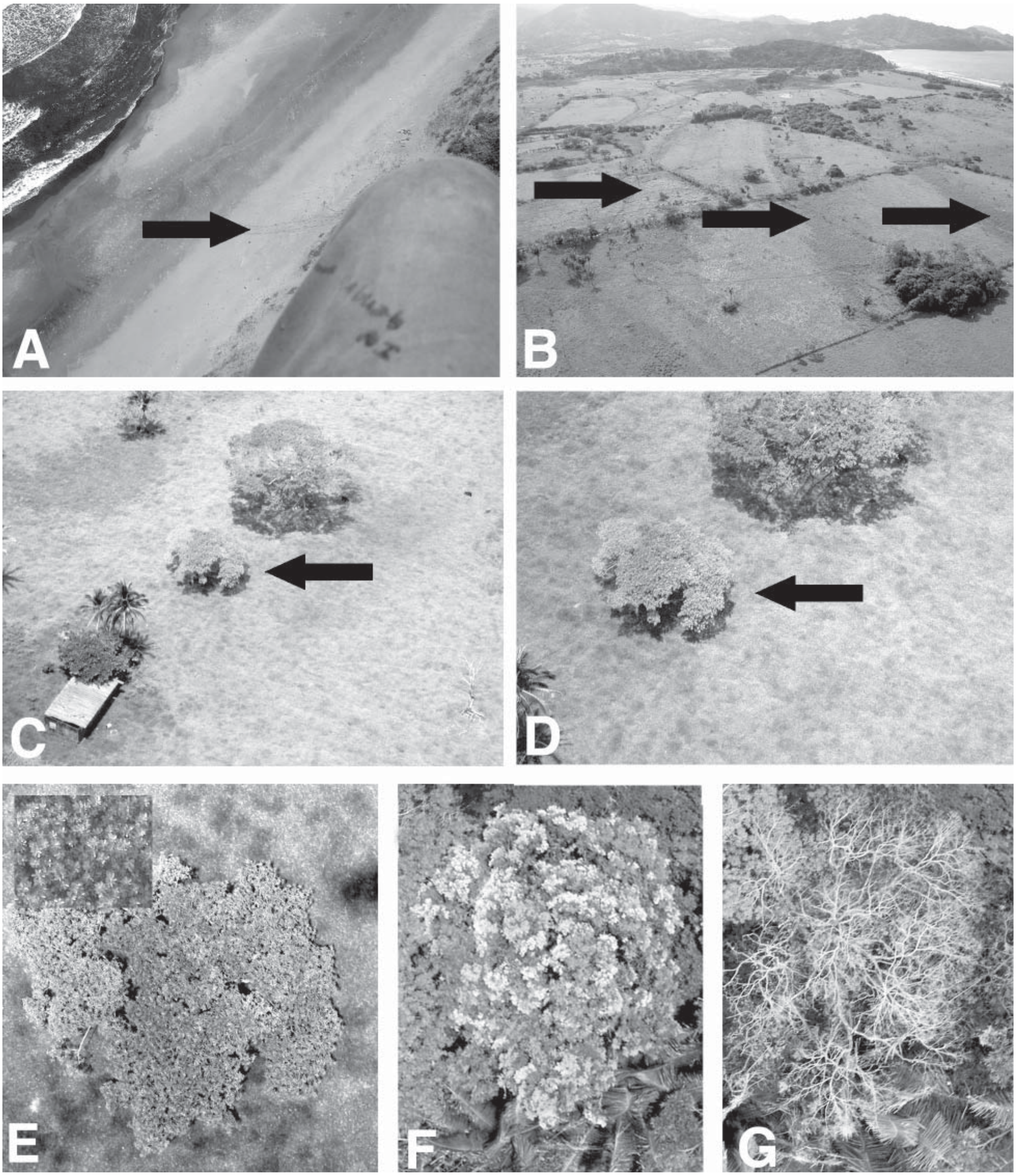

Figure 3. Examples of potential biodiversity applications of powered paragliders. A. Surveying animal populations, e.g. sea turtle nesting. The constant laminar air flow from the ocean and dense air makes flying along the shore the easiest way to fly a powered paraglider. Large sections of coast can be surveyed rapidly for signs of activity such as tracks of sea turtles that emerged the previous night to nest (arrow). Pilot's knee is at lower right. B. Fine scale mapping of organismal distributions. The structure of the shallow wetlands (arrows) on this coastal plain in Veracruz are too small to be shown on maps and are nearly impossible to appreciate from the ground, yet a low-level aerial view clearly reveals their parallel arcs. C-E. Tree crown mapping. Very detailed images of individual tree crowns can be obtained from a powered paraglider. C, D. To locate the tree on the ground, progressively closer orientation photos are

considering the use of a powered paraglider is that a long, straight landing approach, with no major maneuvering on final approach, is essential. This is an even more important consideration for powered paraglider pilots than airplane pilots because of the distance at which the pilot hangs from the paraglider. Though perhaps not desirable as a daily practice, in an airplane, even fairly strong corrections to the final approach can be made successfully. In contrast, turns near the ground can be dangerous in a paraglider. This is because the longitudinal axis around which the pilot-paraglider assembly pivots in a turn is far above the pilot. Therefore, in turns, the pilot swings up and far to the side. As a result, in a turn near the ground, the pilot could be slammed into the ground sideways upon exiting the turn. The ground run itself usually only requires a few running footsteps, meaning that landing technically can be done in a very tiny area. Nevertheless, I prefer as large a field as possible for landing, for three reasons. First, a long, stable approach can be established and potentially dangerous turns avoided. Second, a large field provides many alternatives should hazards block some areas. Finally, a large field is forgiving of miscalculations of glideslope or shifting wind patterns near the ground, both of which can lead to under- or over- shooting the intended landing spot.

Prospects

Because they are so portable, inexpensive, and can fly slowly over small areas and can take off from unimproved fields, powered paragliders have definite potential for many biological applications. That the scientist can personally observe patterns from the air and direct the aircraft over the landscape are clear advantages over alternatives such as helium balloons or remote controlled aircraft fitted with cameras. However, the vulnerability of paramotors to turbulence, difficulty of takeoff, and zero cargo capacity limit their application to observation platforms for calm weather conditions. I provide some examples of uses that I have found for powered paragliders in research, and a list of potential applications that I feel are reasonably feasible for biologists. I do not include some potential applications that are within reach of full-time sportsmen but seem unlikely to be within the range of proficiency of even the most paramotor-dedicated biologist (e.g. fly to a remote mountaintop, alight, collect organisms, and fly back down). Nevertheless, even this level of proficiency provides novel access to many applications. Some examples include:

Aerial photography. Perhaps the most widely useful application of paramotors is aerial photography. The slow speeds and high maneuverability of paramotors makes it possible to take detailed observations of small areas. Because the pilot sits in an open harness and the view is unrestricted by a fuselage or other aircraft structure, the visibility from a paramotor is unparalleled. In calm air, it is possible to let go of one or both of the control lines and to take photographs with standard camera equipment. In flight, the distance of the pilot beneath the wing provides great stability relative to other aircraft because of a pendulum effect. Because the weight of the pilot and engine are so far below the wing, it is difficult to place the aircraft in an attitude that may stall the wing, which is a significant safety feature. Because the paramotor is in constant motion, it is important to use shutter speeds that are as fast as possible. Often, acceptable flying conditions are shortly after dawn or near dusk, coinciding with moments of low light availability. These conditions may prohibit zooming in on objects of interest on the ground. Therefore, digital cameras of higher resolution are useful because they permit cropping later.

Many biologists could greatly benefit from being able to take their own aerial photographs, not having to rely on commercial images. Most obviously, the low altitudes at which paramotors can be flown permits images of remarkably high resolution with standard cameras (e.g. Fig. 3E). Paramotors have also been used for aerial photography by scientists in areas where altitude restrictions prohibit flight at higher levels (e.g. Faustmann and Palmer, 2005). Just as importantly, biologists capturing their own images can ensure that they are as comparable as possible, not only in time of year, but also in level of zoom in the camera, altitude, time of day, etc. All of these factors can seriously affect the analysis of images (e.g. Ahammer et al. 2003).

Fine structure of tree canopies. My use of powered paragliders is to obtain information regarding detailed arrangement of tree canopies. This information cannot be gleaned from conventional aerial photographs for several reasons. First, airplanes fly too high and too fast to take sufficiently detailed images, resulting in excessively

taken. Many trees can be readily identified from the air, such as the *Ficus* below left in C and the *Ceiba* above the arrow in D. E. Once directly overhead, high resolution closeups can be taken of individual crowns, such as these two intermingled individuals of *Ficus* in Veracruz. The inset shows the remarkable resolution than can be achieved, in this case to the level of individual leaves. Shadow of the paraglider is at upper right. F, G. Seasonal phenological differences. Two intermingled individuals of *Cordia alliodora* flowering in the summer wet season (F) and in the dry season in February (G). Powered paraglider images could serve to study the spatial distribution of reproductive structures with respect to the crown.

coarse resolution (cf. Fig. 5E). Second, trees can change rapidly either through growth or breakage from one month to the next, and commercially available aerial photographs are often several years out of date. Similarly, phenological differences can lead to great differences in appearance from one month to the next (Figs. 3F, G), and my study requires images from the same general time as terrestrial field work is being carried out.

Guiding collecting efforts. Targeted collection of specific organisms could be made very efficient with a paramotor. Species of large organisms such as trees are readily distinguished from the air, even in areas of high species diversity (Fig. 3C-G). In my experience, it is entirely feasible to sweep many square kilometers locating the individuals of a given genus (I have done this with *Ficus* on the Gulf coast of Mexico). Likewise, trees can be readily located by flying over dissected terrain that would be time consuming on foot. Paramotors could also be useful for locating collection sites for cryptic organisms strongly associated with a certain habitat type. For example, many wetland plants grow at specific heights relative to the water table. In the coastal plain of Los Tuxtlas, Veracruz, shallow watercourses or depressions make a network whose extent and organization is difficult to appreciate from the ground. However, a view from aloft readily shows their broad arcs parallel to shore (Fig. 3B). A paramotor would be ideal for searching for organisms such as many crustaceans or amphibians that may be found in small or seasonal water bodies that are too small to be shown on maps and are difficult to locate over a large area on foot. That an aerial view often reveals patterns not obvious from the air has not been lost on archaeologists, who have begun to use paramotors to detect and survey archaeological sites (Faustmann and Palmer, 2005).

In some cases, especially work in large flatlands, a worker in a powered paraglider could guide ground vehicles, perhaps coordinating the efforts of various vehicles at once. An aerial perspective would be ideal for guiding a vehicle through flatland dirt roads which are often confusing mazes, or for highlighting likely collecting areas not visible from the road.

Studies of coastal creatures. Because of dense air and laminar winds, powered paragliders lend themselves particularly well to use on the coast. As a result, their use is particularly attractive for applications requiring observations over stretches of coastline. For example, monitoring of sea turtle nesting beaches often requires covering long stretches of beach daily to record where and how many turtles nested the previous night. A powered paraglider could would make such surveys readily accomplished, even over very long stretches of coastline. Nest sites could be documented using GPS and photographs (Fig. 3A) to provide a visual archive of nest sites. Roos et al. (2005) used paramotors in Mayotte to monitor the deployment and densities of *Chelonia* populations in turtle grass beds close to shore.

Aerial animals. The insight to be gained by flying for biologists who study volant animals cannot be overestimated. Three-dimensional use of the atmosphere can best be appreciated from aloft, from whence it becomes clear that most birds fly very low. The shifting patterns of flocks as they pass over the landscape, as well as the use of air flow patterns are potential sources of study. Only to an airborne biologist is it truly apparent the uses that flying animal must make of airflow patterns. For example, the dune in Fig. 2A has a dependable updraft in the afternoons, formed by the sea breeze being deflected upward. Flying animals must be aware of such features and likely utilize them.

Reproductive biology or phenology. Waller and Steingraber (1995) note that trees can be regarded not only as photosynthetic devices, but also as supports for gamete exchange and propagule dispersal structures. Many floral and fruit displays are no doubt directed at flying animals or exposed to the wind, and therefore might benefit from aerial study. Similarly, congregations of animals across the landscape associated with reproductive activity, e.g. bird rookeries or ctenophore blooms, could also be detected, as well as preferences in the positioning of birds, e.g. courting males, in tree crowns. Likewise, phenological changes in virtually any situation, e.g. a tree crown (Figs. 3F, G), can be readily recorded.

Studies of populations and behavior. Estimating population densities of large organisms can be difficult because they may be distributed over a very wide area. Censuses of trees, large mammals, or any other organism large enough to be observed from the air could be readily performed using a paramotor. Likewise, constructions such as burrows, termite nests, crocodilian or turtle nests, and features such as grazing patterns, are all readily revealed from the air.

Emergencies. A powered paraglider could be useful in some emergency situations. For example, during flood conditions a powered paraglider could be used to cross swollen channels quickly to return with watercraft. Likewise, a powered paraglider could be useful in virtually any situation requiring light but essential gear e.g. medicine, small spare vehicle or equipment parts, etc.

Limitations and dangers

This section briefly outlines some of the situations for which paramotors are definitely not suited, and treats some of the salient disadvantages of these aircraft. Because any one of these considerations could be sufficient to make the use of paramotors impractical or even dangerous in a given context, they should be critically examined before contemplating the use of a paramotor.

Weight. The main drawback certainly noticed by everyone who has flown a powered paraglider is the weight of the entire setup. Powered paragliders are touted by manufacturers for their light weight, but with a full tank of gas, harness, helmet, radio, camera, wing, and reserve parachute, the weight can reach some 60 kilograms. Standing on a hot day in a tropical pasture with a helmet and a warming engine on one's back, waiting for the wind to blow just right for takeoff can be extremely tiring. The weight is only a problem when on the ground, because in the air the weight is borne by the wing. Nevertheless, it sometimes takes several attempts to become airborne, especially at high elevation or on hot days (air that is less dense requires a much longer, and more strenuous ground run; see Fig. 2D). Therefore, the use of a powered paraglider in anything but conditions that permit takeoff with very few steps can be hard on one's back or knees.

Turbulence. Because the paraglider is small, light, and has no rigid parts, it is particularly vulnerable to eddies or vortices in the air that can momentarily cause the wing to lose its inflation pressure and collapse. Turbulence can derive from rising columns of warm air, or from mechanical disturbance by an object, e.g. a hill or a row of trees, to the airflow. At several thousand feet, there is plenty of room to allow the glider to reinflate, although it entails some loss of altitude. However, for a scientist taking observations relatively close to the ground, a collapse and the consequent loss in altitude could be catastrophic. Therefore, powered paragliders are best used in calm conditions, never any lower than is strictly necessary, and always with awareness of sources of thermal and mechanical turbulence (see Pagen, 1992).

Unreliability of the engine. The very light weight of powered paraglider engines comes with several tradeoffs. The most noticeable is that they generally have only one cylinder. Obviously, in an aircraft with a single-cylinder engine, the loss of that cylinder signifies the end of the flight. However, careful selection of flying areas ensures that an engine failure is not a dangerous event. As with any light aircraft, the most judicious flight path is one over appropriate terrain and with sufficient altitude that an engine failure would permit gliding to a safe landing area. For observation of tree crowns, I fly only over lone trees or forest remnants surrounded by pasture to permit safe landings in the pastures (e.g. Fig. 3B-D), rather than flying over continuous forest.

Eye and ear protection; comfort. Because a paramotor pilot sits in the airflow and not behind a windscreen, it is possible that a collision with a bird or passage through a swarm of bees could damage the pilot's eyes and hamper a safe landing. As a result, I wear heavy duty goggles (with prescription lenses). Also, between the rushing air and howling motor, a paramotor also makes few concessions to noise reduction. Therefore, ear plugs are essential. Finally, a paramotor is far from comfortable. Before takeoff, all of the considerable weight of the engine is borne by the pilot. Different paramotor models may have differing attachment points at which the wing connects to the harness. These options have advantages and disadvantages. High attachment points lead to greater pendular stability but may require the pilot to maintain his or her arms upheld awkwardly for long periods, which may be unacceptable for those with shoulder problems.

Inadequate training. In most countries, the piloting of paramotors is completely unregulated and no training is required. Unfortunately, trainers are also not regulated or evaluated. There are as a result a large number of "instructors" that are willing to provide very brief training. The atmosphere is a complex and foreign environment, and aerodynamics are often mysterious or counterintuitive, factors making adequate training in this disorienting realm essential. The training at my paragliding school consisted of nearly two weeks of reasonably thorough schooling in handling of the wing, followed by a completely irresponsible two hours' training using the motor (see also the following section). Paragliding instructors are usually sportsmen who have decided to make a living from their hobby; in my experience their aerodynamical knowledge is largely empirical and often uncertain. I strongly recommend consulting aviation textbooks to complement any paramotor training (e.g. Machado, 1996; Thom, 1997; Langewiesche, 1944, etc.).

Torque effect. One consideration that affects the use of paramotors also illustrates the danger of inadequate aeronautical knowledge. In all single engine aircraft, the physics truism that every action has an equal and opposite reaction is particularly relevant at high engine revolutions, when the spinning of the propeller is opposed by the tendency of the aircraft itself to revolve in the other direction. In an airplane, this tendency is counteracted by use of the rudder. During my paramotor training, I asked my instructor how the this torque effect is dealt with in a paramotor, which has no rudder. He (erroneously) replied that my paramotor was the product of ingenious German engineering that reduces the torque problem to the point of irrelevance, when in fact it is about as feasible as rendering gravity irrelevant.

In reality, in a paramotor at high engine revolutions, it is the pilot himself that turns somewhat in the opposite direction of the spin of the propeller. This has the effect of pulling one side of the wing down relative to the other, causing a turn in that direction when in flight. High engine revolutions are always used on takeoff, and the subsequent torque effect produces a gradual turn on takeoff. It cannot be overemphasized that this climbing spiral turn must be accepted when taking off at full throttle, and must not be opposed by using opposing control inputs, because this may stall the wing and cause a precipitous fall, possibly from a dangerous height. Therefore, paramotor pilots must be sure of the direction in which their propellers spin and must plan on accepting a spiral turn in the opposite direction on takeoff. This plan must include assessment of hazards in the anticipated flight path, and may mean that some fields cannot be used.

Unsuitable flying areas. Many areas that would be extremely interesting to overfly provide no safe landing areas in the event of an engine failure. In some areas, it may be best to leave them for observation with more conventional aircraft, but in many cases it is possible to find a useful compromise. Such areas include highly urbanized zones, those crisscrossed with electric lines, areas of continuous forest, extensive wetlands, and desert areas that, albeit relatively open, have many columnar elements (e.g. the vast stands of *Fouquieria columnaris* and *Pachycereus pringlei* in the central desert of Baja California) that could snag the wing on landing. The strategy I have adopted for observing tropical tree crowns is to fly over forest fragments or individual trees in pastures. When overflown at sufficient altitude, even if an engine failure occurs, it would still be possible to glide to a safe landing in the adjacent pasture. This may not be as desirable as flying over primary forest, but at least some interactions between trees can be observed, and the safety margin is considerable.

The need for proficiency. Piloting any aircraft safely requires the maintenance of proficiency, which in turn requires regular practice, in my experience preferably weekly. Using a paramotor only during occasional field trips ensures that the pilot is never flying with an acceptable level of proficiency. In addition, as with any engine, the paramotor must run regularly to maintain its proper functioning. Thus, the use of paramotors implies a time commitment beyond its use in the field. Likewise, it may be technically possible for some paramotor pilots to land in very small areas, e.g. on dirt roads, on rooftops, or in tiny clearings. However, as discussed above, a large field (my generous personal minimum is equivalent to four football fields) is in practice more realistic and advisable. Therefore, despite the feats of sportsmen or what sales promotions may say, the average biologist should not expect to be able to take off and land safely from very small areas.

Accidents. Based on data from nonpowered paragliders, the bad news regarding paragliders is that, should an accident occur, injuries are fairly likely (Fasching et al. 1997) Schulze et al. 2000, 2002). Moreover, these studies, taken together, show that injuries occur throughout the phases of flight (takeoff, inflight and landing). Too few formal data are available to say whether or not paramotors are any safer or more dangerous than their non-powered counterparts. In addition to these hitting-the-ground type accidents, it might be suspected that the presence of a spinning propeller (the tips of even the modest sized propellers used on paramotors travel at more than 500 km/h at moderate rpms) and gasoline, both extremely hazardous, would make powered paragliders comparable or even more dangerous than nonpowered paragliders.

Conclusion

Powered paragliders clearly have a potential role in many biological applications that require a view from aloft, while taking into account a variety of practical considerations. For example, because they are heavy and awkward on the ground, they are clearly not an option for those looking to move objects or people from place to place. Likewise, because they are vulnerable to turbulence and have, by aviation standards, unreliable engines, they are only suitable for observation over areas where a safe landing can be effected and where wind or turbulence are not excessive. A space to one side of the takeoff that is free of obstacles to allow a torque-induced turn on takeoff also needs to be ensured, and the need for a large field for a stable landing approach must be taken into account. Biologists with knee or shoulder problems, or those wishing to work at high elevation or other high density altitude situations should be particularly aware of the potential problems involved. Finally, as with any aircraft, it is necessary to make a commitment to regular practice. Despite these limitations, paramotors have many advantages over other types of aircraft, one of the major ones being that paramotors are foot launched and landed. As a result, they can operate from fields that are too rough to serve for aircraft landing gear. Fairly tall grass or shrubs, or uneven soil surfaces are often sufficient to prohibit the landing of conventional aircraft. In contrast, any large field that a person can jog is suitable for takeoff and landing of a paramotor. Other strengths of paramotors are their portability, low cost, and very slow flying speed, which makes these aircraft ideal candidates for use as aerial observation platforms by field biologists.

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