Journal and Proceedings of the Royal Society of New South Wales, vol. 146, nos. 447 & 448, pp. 44-54.
ISSN 0035-9173/13/010044-11

Invited Discourse: The Invention of the Modern Pendulum Weight Shift Flexwing Hang Glider in 1963

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Abstract

Safe foot launched flight was made possible by the invention of the modern hang glider, controlled by a pendulum weight-shift device. The optimal wing geometry of the hang glider, and correct placement of the pendulum weight-shift device, were determined by trial and error experimentation in natural outdoor conditions. Development of the modern hang glider was based on shop-bought or second hand materials, and did not involve any laboratory-derived data or research funding

Introduction

Figure 1. Water ski kite of the 1960's era.

In January 1963, as a member of The Grafton Water Ski Club, I was approached to design, build and fly, a Water Ski Kite for the upcoming Jacaranda Festival Water Ski Carnival in October/November of that year. This request was made because club members learned that I built and flew a Benson gyro-glider, with rotor blades of my own design. It is worth noting that I found the auto gyro difficult to fly, with sharp control response, I describe as twitchy, with little natural stability. I regard them as very dangerous to fly.

It is now just fifty years since that request was made. The 1950's to 1970's was boom time for water skiing. The rich and famous and those seeking the atmosphere and limelight flocked to any water way, suitable for the activity. Water Ski shows were common. They had competitive events such as slalom, where skiers make dramatic, sharp turns at speed around buoys anchored by rope to the bottom of the river or lake. Trick skiing, ski jumping by skiing up an inclined ramp at high speed, launching into the air and travelling some distance before landing, hopefully, upright on the skis. Other non-competitive events thrilled the crowd such as the "ski ballet", where many attractive young ladies would ski in formation and perform acrobatics. The show would usually end with the main attraction, being the flight of a water ski kite, always seen, as the most dangerous and daring feat. The Grafton Jacaranda Festival Water Ski Show was one of the biggest in Australia. The riverbank formed a natural amphitheatre. It is an ideal location. The income generated financed the club activities for the next year. Thus the additional attraction of having a water ski kite for the show was a strong motivator for its inclusion.

I had built and flown model aircraft and kites during my childhood years, many of my own design. I was passionate about everything to do with how aircraft fly and all aspects of their design. And, like many model makers, had delved deeply into aerodynamics and structures. At thirteen and fourteen years of age I was reading about aerodynamics and engineering at university level. I had never seen a water ski kite, but had a few photos to go on, and did not consider that the project was going to be a difficult problem. I built what I considered as a representative five sided scale model. It flew quite well, but when a weight was suspended below the kite representing the pilot, it became unstable and the various adjustments and modifications tried, resulted in only minor improvements. Not enough for me to be confident to make an investment in a full sized, person operated device that was in anyway safe to fly. I then considered other kite, or wing-like devices. I was looking for a stable controlled descent as part of the device characteristics, with an angle of descent of 1:1 or 45 degrees.

Previous to the request to build a kite, I had made a model glider based on the flying fox wing. Flying foxes were a common sight around Grafton at that time and I was fascinated by their good glide, the simple structure of their wing and the fact that the wing was flexible, as though it was made of fabric. The model had a good glide, and perhaps a low aspect ratio design based on the fox wing might be an answer to my problem. Even so it would be far more complicated than the simplicity of the water ski kite based airframe, and very expensive.

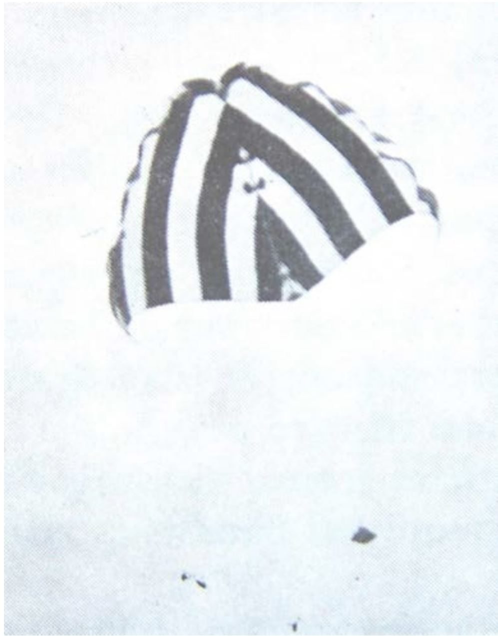

Figure 2. NASA research para glider wing from the 1960's.

I had discussed my quandary with a number of club members and one member presented me with a magazine that included a photo and article describing an experimental gliding parachute that was being developed by NASA to return space capsules to earth safely under controlled guidance. I saw an exciting possibility that a new gliding device could be created by incorporating the water ski kite airframe into the gliding parachute.

The parachute consisted of two completely flexible semi-conical lobes. I could see that if the nose to tail element of the water ski kite (keel) was secured to the centre section of the gliding parachute, and the cross member (main spar) was installed, bolted to a solid member (leading edge), fitted to each leading edge of the parachute and connected to the keel at the nose, I then had a simple air frame, that could also incorporate the same lower "U" construction that supports the operator of a water ski kite. Additionally there was a chance that I might attain my "45 degree" parachute like safety descent. There was also recognition of a direct connection in my mind with the bat wing model I had built earlier. The "half semi-cone" shapes of the gliding parachute almost matched the wing tips of my bat model. The low aspect ratio of my bi-conical wing was also seen as a strong possibility of a slow, steep and hopefully stable descent in an emergency. I made the decision to proceed to experiment with models of my concept. I imagined a double lateen sail arrangement as an easy solution to forming my twin semi-cones.

Figure 3. Australian Flying Fox, showing its wings.

Figure 4. Lateen sail – a semi-conical wing, invented by the Egyptians thousands of years ago.

Method

The first step was to design and build models of what I then called "the wing". Air frames were made from timber boxes in which fruit was transported and sold in during the 1960's. The timber was a light soft pine, 6.35mm thick, trimmed down to a square cross section. The centre section length chosen for my model was 500mm. Thus 50mm was 10% of the model length and therefore, easier to apply percentage values, in determining centre of gravity points etc. I called the centre element the "keel". The leading edges were made the same length as the keel, the leading edges were hinged to the keel at the nose, and I used varying lengths for the cross member (main spar) to vary the nose angle. Light brown paper was used as the wing/sail material. I experimented with varying "total" nose angles from 70 degrees to 110 degrees in 5 degree increments. The pattern cut of the sails at the nose angle was 10 degrees more than the frame nose angle. I was surprised at the glide obtained. I found the widest nose angle, 110 degrees, gave the flattest glide. But was less stable laterally and directionally. I settled on 80 degree nose angle with a 90 degree wing sail nose angle, this gave the best all round stability with a better glide than I required, and I have to admit that I felt some excitement that I was developing a glider capable of real gliding flight. Even so I considered that the drag created by a human body dangling beneath the wing would spoil the glide, and thus I would have my 45 degree decent. However, any sort of a glide would require control to avoid descending into the riverbank, or worse an assembled crowd. I now had a problem of control to solve.

The solution came in a serendipitous manner. I had taken my young daughter to a local park where she loved the swings. I was swinging her backwards and forwards and sometimes in a circular motion, when it occurred to me that if I were to fit a swing to the "keel" of the wing, and used a fixed bar to work against, then I may achieve three axis control, via the means of weight shift. I reasoned that the frame, usually suspended below the main spar of a water ski kite, could serve this purpose. This meant the overall design and concept of the structure was still heavily influenced by the water ski kite configuration. To test my theory I decided to build a "half sized model" with a wing area of 7 square metres. The nose angle chosen was 70 degrees, which was very stable directionally, and therefore more difficult to move, side to side across the boat wake. The reason for this was that the model was not intended to fly, only to prove if my weight shift concept would work for lateral control, and able to move the wing and skier across the wake, side to side, by aerodynamic effect alone. It was also an opportunity to solve construction problems that may occur with a full sized wing intended to fly.

Rough drawings were made and materials for the construction obtained, mainly from the local tip. The only items purchased were banana plastic sheeting for the sail and electrical sticky tape to seal the lapped joints formed when making the sail. Every other item was obtained from the local tip or the scrap box in my garage.

This test model was trialled in May 1963 on the Clarence River and results were strongly positive. There was sufficient lift to just support the weight of the operator and strong aerodynamic force, developed by the weight shift action, easily moved the wing and skier from side to side across the wake of the ski boat. The tests were conducted at 68kph. Thus pendulum weight shift for aircraft control was a reality.

Figure 5. Half-size model waiting for a test run in 1963. Pilot John Dickenson.

Figure 6. The half-sized model under test. Note that it was never designed to actually fly. Pilot John Dickenson.

Design and construction of the full-sized model

As mentioned earlier funds were short and the risk this experiment may be a complete failure was uppermost in my mind. Therefore, a throw away approach was employed to the selection of materials. For the wing sail blue banana plastic was used as per the half sized model. "Blue Banana Plastic" as it was known, is plastic sheeting 0.001mm thick that is sold in rolls, 0.9m wide, and cut into short lengths by the banana farmers of northern NSW, who wrap the blue plastic sheet around the young bananas to protect them against the strong sun, and cold at night. The blue plastic sheeting could be bought very cheaply. I carried out tests to determine the load the plastic sheet would carry per square metre. A loose sample was taped over the top of a bucket, and dry sand was poured into the plastic sheet which then formed into a dish shape by the weight of the sand. The weight of the sand was equal to 4.5kg applied to an area of 0.093 square metres without any sign of failure. Proving that the plastic sheet sail could safely lift a 725kg flight load, ten times the weight of the pilot and glider. Oregon timber was chosen for the leading edges and centre 38.1mm x 38.1mm square, with chamfered corners, straight grained no warps, no knots. It also had the advantage in it would allow the wing to float.

The blue plastic sheeting was cut into suitable lengths, then overlapped directionally wing tip to wing tip, and secured together with blue electrical sticky tape. The excess was cut away to form a "sail" of sufficient area to form the bi-conical wing. The sail was attached to the timber leading edges and keel using rounded timber strips nailed in place with 25mm steel brads.

The main spar was 3.048m long, 38.1mm outside diameter, TV antenna mast quality aluminium tube, with a wall thickness was of 1.6mm. It was short of the length I required, but it was all that was available at the time. Turned hardwood dowels were fitted and glued into the main spar tube at the centre connection, and at each end to provide sufficient strength at these points.

The straining wires were as per TV antenna mounting, more than 10 times the estimated strength required in flight, lowest cost and readily available.

6.35mm diameter hardware store quality cad plated hexagon bolts, were used at airframe joining points, much stronger than expected flight loads. 6.35mm shaft thickness 'D' shackles, connected the flying wires to the control bar mounting points, which were 5mm thick steel tabs welded to the control bar. The total cost of all components then, was $24.00.

Selection of the sail area was based on the idea that a 1:1 descent angle was possible, a parachute-like descent in full stall. The area of parachutes is typically 16.3 square meters. 14.9 square meters area was chosen since, hopefully, any such emergency descent would be into water and a higher descent rate than a parachute would be acceptable and still provide a safe landing.

The timber components were subjected to strength tests by hanging them from a beam in the garage, and suspending weights from them equivalent to ten times of the total load the component was to carry. It was shown in a crash during test flights that the wing was a lot stronger than pre-flight structural testing.

Establishing control
A relationship between the pilot, control bar movement, and angle wing attack needed to be worked out. The pilot would be suspended at the centre of aerodynamic lift. Tilting the nose down would effectively shift the pilot's weight forward, this was accomplished by moving the control bar rearwards towards the pilot's stomach, thus causing the wing to dive, and moving it away from the pilot, would induce a climb. It would also, at maximum movement away from the pilot, and if the relationship was correct, enter a controlled stall, with the desired 45 degree descent. Conventional aircraft wings generally operate angles of attack between 2 degrees to 16 degrees, with best average cruise angles of 8 degrees. The very extreme washout of my wing made it difficult to determine the average "desired" angle of attack of the wing, of around 8 degrees. By using the maximum movement my hand could reach outwards from my stomach, I measured 61cm. I decided on a wing tilt of 22 degrees, to give me the full control into deep stall I was looking for. A little simple trigonometry gave me a nominal lever length of (152.4cm). The control bar was given a length of 106cm and outside diameter of 30mm. Dimensions were determined as a result of the practical experience with ½ sized model test. Hessian straps were attached to a timber board 152cm long x 25cm wide to form the seat and suspension from the keel to the seat. The seat was hung so that it was 38cm below the control bar when the seat straps were forward against the control bar. This means that minimum angle of attack of the wing occurred, when the control bar was pulled back against the straps, and would be in maximum dive. A guesstimate was made, based along the line formed along the top of the sail looking at the side view, from the nose to the trailing edge of the sail, as being the zero angle of attack. The components of the wing were assembled and the wing made ready for testing. As it turned out, the angle of attack estimate was a very serious error.

The first test flights:
Saturday afternoon 7th September, 1963
The wing was pre-assembled and checked, prior to transport to the beach adjoining the Water Ski Club on the Clarence River at Grafton. The weather was cool, but fine, with a light southerly breeze. At the beach, the wing was reassembled and made ready for testing.

The wing was connected to 42.8m of ski rope, two, 21.4m lengths, normally used by water skiers. If flight was achieved it was intended to limit the maximum height attained around 9m to 12m, by varying the boat speed.

Figure 7. John Dickenson taxis out to take off, and make his second attempt at a successful flight with the full-sized Mark 1.

I made the first attempt with seat connected to the most forward centre of gravity point at 45% of keel length from the nose of the wing, two other connection points were set at 47.5% and 50% of keel length, tests on the 80 degree nose angle model showed 47.5% as the average centre of gravity.

Figure 8. First successful flight of the Mark 1 under full control.

A satisfactory start was made and the wing settled above me, and despite every attempt to attain a positive angle of attack, the wing just fluttered, without any sign of lift at all. I was carrying the full weight of the wing, 20 – 23kg. I returned to the beach utterly exhausted. Since at that time my prowess as a water skier was 'C' grade, it was thought that a more competent skier may have better success, and do a better job of placing real weight on the swing seat, thus inducing an angle of attack, and hopefully flight.

Our following test pilot, Norm Stamford, made the next attempt with exactly the same result, no sign of lift at all.

Test pilot number three was much taller and heavier than the earlier would be test pilots, but, in view of the total lack of lift on the first trial runs, the seat was moved to the rearward mounting point. All was made ready, the boat accelerated, the jump start affected, and our pilot shot up 24 metres. The pilot pulled the control bar as far back as he could, the boat stopped dead at the same instant, and test pilot number three plunged straight down 24 metres. He was not physically injured, but severely shaken. The wing proved its strength and was undamaged.

The wing was made ready again and our fourth potential pilot prepared for flight. The seat suspension point was moved to the central mounting point at 47.5% of keel length. Rod Fuller, our Club's top skier and district champion, made an easy jump start, settled into the seat, the wing was carrying his weight easily. The boat was accelerated into the breeze and the wing climbed steadily into the air. It continued to climb to an altitude limited by the length of the rope, i.e. 42.8m. Regrettably the control bar was set too far rearward and Rod could not pull the wing down, and the wing was flying close to stall. Fortunately the boat driver, Patrick Crowe, realised what was occurring and managed to swing the boat in a wide curve and gently lower Rod back to the water by running down wind, necessary to keep the boat on 'plane'. Rod and the wing were returned safely to shore. Following discussion with Rod, I replaced the fore-aft wires and reset the control bar forward, which effectively reset the angle of attack of the wing.

For the second time I made an attempt to get the wing into the air under full control. This second attempt was a complete success. Once settled into the seat, which I found very comfortable, the take off was easy and I had full control of the wing. The flight varied between a maximum altitude of 16 metres, and down to 4 metres. Pitch and lateral (turn) control was excellent, the wing was a delight to fly, and perfectly stable on every axis. I also found that the wing was gliding on a slack rope, a glide that was flatter than anticipated, and I realised, while in the air, that I had developed a new form of glider with the potential for foot launched gliding flight. The flight was not timed exactly but was 20 to 30 minutes. I packed up my wing, loaded it on the car, very pleased and excited, the other club members equally so. Additionally we had our big attraction for the upcoming Jacaranda Water Ski Carnival. Within days I had lodged a patent application, entitled, "An Improved Gliding Apparatus". Patent pending No. 36819/63 was granted, dated 11th October, 1963. I called my new flying machine the "Ski Wing".

To establish an effective research program to develop and fly the wing, it was necessary to devise procedures for take-off, during flight, landing and ground handling. Additionally, following the successful test flight, two important matters required attention:

1. Review of the wing structure as exposed by flight experience.

2. Learning to fly the wing with its totally new form of pendulum weight shift control.

Structural modification
During following flights it was found that the keel was flexing in response to varying flight loads.

A simple modification solved the keel flexing problem. The control bar had a metal tube strut welded at each end, and were bolted to the main spar and leading edges. The ends of the struts were moved to the centre of the main spar, thus forming a triangular structure which I called the "A" frame. A wire was connected from each end of the base of the "A" frame (the control bar) to the ends of the main spar thus forming an immensely strong system to carry the flight loads.

The pilot suspension point was moved backwards and forwards from the initial test flight setting, to obtain the optimum location, and it was found that the initial setting was best at 47.5% of keel length from the nose of the wing.

No other structural changes were made to the wing prior to its debut at the Jacaranda Water Ski Carnival.


The Daily Examiner

Carnival

A. Explains
hy There Is
Be Election

HE'S AIRBORNE ABOVE THE CLARENCE RIVER WITH A SKI-WING

Still Searching
For Whaler

DEFENCE SPENDING
BY LABOR GOVT.

Relationship With
Australia Harmed

Figure 9. The report of the ski wing in action at the Jacaranda Water Ski Carnival that appeared in the Daily Examiner, Grafton, 21 October 1963.

Process of controlling the wing, take off, flight and landing
During one of the many flights leading up to the carnival I lost my ski while taxiing at speed behind the boat (we only used one ski and employed a jump start). I was dragged underwater for some distance. As a result I designed and constructed a release mechanism that was fitted to the boat the following weekend. The release was employed for every flight from then on until we ceased flying at Grafton in November 1965.

It was essential to establish a routine of understanding between the pilot, observer and boat driver. It was particularly important for the observer to communicate the instructions clearly to the boat driver. The pilot nodded his head up and down for more speed, and horizontally for less speed. The boat driver would indicate his intentions to the pilot directly with hand signals.

Figure 10. Rod Fuller shows off the wing with the "A" Frame modification, October 1963.

Transition: ski wing to hang glider

Although it was obvious from the first successful flight that the wing as flown, was suitable for foot launched soaring flight, I realised that there was an opportunity to fully develop the wing and methods of launch and flight control, with great safety over water in towed flight. Additionally we could climb to height and release into gliding flight, perform manoeuvres, and develop non-towed landings.

There was a problem. The wing, now called the "Mark 1" flew too slowly to allow full testing behind a speedboat. I needed a wing that would take off at 40 kph when the boat was up and planing. The Mark 1 wing would often take off when the boat was hardly moving. As a consequence, in January 1964, I built a smaller wing Mark 2 with 4.27m long leading edges and keel. The construction was all aluminium airframe, but I retained the banana plastic wing sails and, with a release system to disconnect the glider from the tow rope, which was fitted to all following gliders built, thus allowing free gliding flight.

Figure 11. Release mechanism fitted to the ski boat rope attachment point to disconnect the Ski Wing in an emergency. Used from October 1963 to December 1965.

After very few flights, the banana plastic sail that had been attached to the metal airframe with contact adhesive, started to de-laminate. The Mark 2 also flew too slowly to suit my testing plan, so the Mark 2 was scrapped. In February 1964 I completed Mark 3, consisting of 4m timber leading edges and keel. The cross section of the timber was as per the earlier Mark 1, 'A' frame dimensions as per the Mark 1, release system, and a design change to a fully folding air frame and "A" frame, allowing easy transport and rapid assembly and re-packing.

The Mark 3 matched the boat speeds perfectly, was easy to fly and immensely strong.

Take-off air speed	37 – 40 kph.
Stall speed	32 – 35 kph.
Maximum speed	75 kph.

Figure 12. Amy Dickenson displays the fold ability of the Sky Wing. The wing was constructed to aircraft standards in late 1964.

Figure 13. The Mark 3 in gliding flight in early 1965. Pilot Rod Fuller.

However, despite my estimated maximum airspeed, on one flight, at a Water Ski Show, I found myself being towed by a maniac boat driver and I estimate the 'air' speed into the prevailing wind as "at least" 110kph.

Figure 14. Botany Bay record endurance flight attempt for towed flight of 6 hours, April 1969.

Over time, as finances would permit, the Mark 3 design was up graded to aircraft engineering standards, with aluminium airframe, nylon sail fabric, and stainless steel flying wires, bolts and fittings. Battens were fitted in the wing trailing edges to prevent flutter. By adding battens to the trailing edges of the wing sail and making a scalloped curve of 6% of the width between the battens, a noticeably flatter glide, with increased speed due to the lower drag, was achieved. By the beginning of 1965, the fully developed Mark 3, scaled up to the size of the original Mark 1 was the template for the Standard Hang Glider for more than the next ten years, and is known today as the "Dickenson Wing".

Fifty years later most hang gliders still employ the same basic five element air frame namely, keel, main spar, leading edges, "A" frame and the essential Pendulum weight shift control.
Powered Micro-light aircraft development was initiated by adding an engine and seat to the bi-conical "Dickenson Wing" with pendulum weight shift control. In October 2012 I was awarded the "Federation Aeronautique Internationale" "Gold Air Medal". Regarded as aviation's highest honour, the sponsors of the award successfully claimed that more people have

learned to fly with the "Dickenson Wing" than any other type of aircraft in the history of flight.

John and Helen Dickenson

(First draft of manuscript received 26 February 2013; final manuscript accepted 12 June 2013.)

John and Helen Dickenson John Dickenson has had a diverse career as an engineer, involved in a many wide-ranging projects, such as the pioneering radio telescopes built near Badgerys Creek in the early days of radio astronomy. He has received numerous awards for his contributions to aviation, most notably the Federation Aeronautique International (FAI) Gold Air Medal in 2011, together with a Presidential Citation from the United States Hang Gliding and Paragliding Association and the Oswald Gold Medal for the most notable contribution to aviation by an Australian by the Royal Federation of Aero Clubs of Australia. He was awarded an Order of Australia (OAM) Medal in the Queen's Birthday Honours of June 1996. His daughter, Helen, has a BA from Sydney University and a MA from Macquarie University.

John Dickenson
Image by Evan Okland from the Ken de Russy collection.