A UK-centric history of the testing and certification of fuse-tube design microlight aeroplanes.

Guy Gratton
Brunel Flight Safety Laboratory, School of Engineering and Design
Brunel University, Uxbridge, Middlesex UB8 3PH

Summary

The first fuselage tube microlight aircraft appeared in USA in 1977. At this time there were no airworthiness requirements for such aircraft. Licensed production commenced in France in 1981 and subsequently in Britain. The first requirements were the British BCAR Section S Small Light Aeroplanes, which became mandatory for new types in 1984 and has formed the basis for subsequent European requirements.

In about 25 years this family of aeroplanes has gone from single seaters climbing at 250fpm and achieving 40 knots in level flight to 2-seaters climbing at over 1000fpm and touching 90kn in level flight. Many, although certainly not all, have been designed and tested by people without formal qualifications in aeronautics. They have been build in thousands, and continue to be flown in very large numbers.

Simple flight test procedures have been developed which are suitable for pilots who have not been trained in flight test. These include longitudinal stability, spin recovery and adjusting propeller pitch and maximum level speed to maintain an acceptable margin below V_{NE}.

1. Introduction

In the early 1980s, an American model aircraft designer named John Chotia came up with a simple concept for a single seat Ultralight Aeroplane [1] which was to inadvertently spawn at-least four subsequent generations of small aeroplane, each of which would create both a devoted private pilot following, and its own set of flight test and certification issues. These developments also shadowed the development of microlight certification practices in the United Kingdom and other countries, such that this development also shows the progression of best practice particularly in microlight flight testing.

The Weedhopper (Figure 1), pioneered a new configuration which has become known as fuse-tube construction (a corruption of “fuselage tube”). A single large tube of about 100mm diameter ran from nose to tail of the aeroplane above the pilot’s head – on this tube was mounted the horizontal and vertical stabilisers and control surfaces, the wings and the engine, whilst below it was suspended a framework cockpit underneath which was fixed a tricycle undercarriage. Fuel was pumped from a single transparent tank behind the seat. The wing, fixed tailplane and vertical stabiliser all consisted of leading and trailing edge circular section tubes, supported by internal bracing, with a wing surface of non-porous polyester fabric pre-formed before being stretched over the flying surface framework. In the case of the mainplane, the fabric was supported by narrow aluminium alloy battens formed to create the required aerofoil shape and inserted into pockets stitched into the wing surface. The wing used a leading edge sweep of about 5° but straight trailing edge, the tail structure was essentially cruciform with the fin and rudder areas divided approximately 50/50 above and below the tailplane and elevator.

Figure 1 Chotia JC-24b Weedhopper

2. History

The first aircraft known to have used the Fuselage Tube design was the Chotia JC24 Weedhopper: a single seat tricycle undercarriage aeroplane which first flew in 1977 and enjoyed around 20° of total dihedral, and a side-stick control that operated a conventional elevator in pitch, and the rudder in the lateral sense. The aeroplane lacked any moving control surfaces on the wings, and hence had 2-axis controls in flight. On the ground, the pilot's feet rested on bars extended from the steerable nosewheel in a similar mechanism to the handlebars of a bicycle, where the pilot pushes right to turn left. The powerplant was one of several 2-stroke engines driving fixed pitch propellers and was normally suspended below the fuselage tube. The aeroplane was designed by John Chotia who died on 27 October 1981 test flying one of his own designs, the same year in which they were first introduced to the UK and Europe.

Despite being arguably obsolete by the standards of the 1920s, let-alone the 21st century, the Weedhopper remains in production in the USA [2]. The true adoption of this design configuration is in France, where licence production of the JC24 commenced in 1981 by the French company Ultralair who subsequently also marketed the larger but substantially similar 2-seat AX2 variant (still marketed in the USA as the Weedhopper 2-place using a Rotax 503 DCDI engine). This model enjoyed some small market success but suffered against a maturing worldwide ultralight market where much of the competition was utilising (relatively) advanced design features borrowed from larger aircraft, such as ailerons, windshields, doors and "push-right, turn right" nosewheel.

This led to development of an improved model introducing many of these features, which was known as the AX3 about 1991. Design changes between the AX2 and AX3 were substantial and successful, but French production of the AX3 was short lived due to failure of the company, who overextended themselves on the development of a further improved aircraft known as the Europa.

Before the demise of Ultralair, the rights to manufacture the AX3 were bought by British company Cyclone Hovercraft (later Cyclone Airsports and now after several intermediate identities P&M Aviation), who had also recently taken the UK import agency for Rotax 2-

stroke engines, originally developed for applications such as snowmobiles, but increasingly popular on microlight aeroplanes. Cyclone were also closely associated with weight-shift microlight manufacturer Solar Wings, who were developing expertise in meeting the newly introduced British certification requirements for microlight aeroplanes[3]. Despite these requirements being the most demanding in the world at that time, very few modifications were required to obtain UK certification in 1982. Sales of the AX3 were healthy, and a later development of the slightly heavier and more sophisticated AX2000, led by designer and test pilot Dr. WG "Billy" Brooks, continued this trend.

Figure 2 Cyclone AX3

Rights to the Europa however transferred to the Franco-Indian aircraft designer Joel Koechlin who moved the project to the Bangalore based company Raj Hamsa – moving development of the Weedhopper concept to a third continent. This aircraft was developed over several years to become in 1993 the X'Air which, with a 450kg (992lb) MTOW was a substantially larger and heavier aeroplane than the AX3, and required considerably more power – the 52hp air cooled Rotax 503-2V engine normally fitted to the AX3 would not provide adequate performance, but the relatively unreliable 65hp water cooled Rotax 532 engine had recently been replaced with the similar but more sophisticated Rotax 582/48-2v engine which suited the airframe very well. The initial market for the X'Air was in India and France where regulations permitted sale of a 450kg MTOW aeroplane with minimal requirements for regulatory compliance.

In 1999, the UK converged belatedly with what had become through consensus a common European microlight aeroplane definition at 450kg MTOW, with the introduction of substantially new regulations[4] (arguably part of the route to a later US based initiative of Light Sport Aircraft, or LSA at 600kg); this had been eagerly awaited and led to a significant influx of new heavier types (compared to a previous UK microlight limit of 390kg). Of these, the first 450kg microlight to obtain certification in the United Kingdom was the X'Air, fitted with Rotax 582/48-2v engine, imported as kit planes by the specially formed Camelford and Wessex Light Aeroplane Company (now the Wessex Light Aeroplane Company).

Figure 3 Raj Hamsa X'Air (UK designation X'Air Mk.1)

Sales of the X'Air (termed X'Air Mk.1 in much UK documentation) were brisk: several hundreds of aeroplanes and aeroplane kits have been sold globally, and numerous variants have been tested and certified – usually distinguished by a wide variety of 2 and 4 stroke powerplants [5]. However, there had been particular pressure in the French market to reduce wing area, necessitating the introduction of flaps (most countries using the 450kg microlight definition required a maximum stall speed Vso of 35kn CAS). This led to the introduction of the flapped X'Air F, marketed in the UK as the X'Air Falcon (Figure 4). Total production of X'Air and X'Air F models has exceeded 1300 kits, mostly sold to private owners outside of India, although some Indian operators exist including at least one police force. (A more recent X'Air Hanuman (X'Air Hawk in the UK) model is a largely unrelated design.)

Figure 4 Raj Hamsa X'Air F (UK designation X'Air Mk.2 Falcon)

Returning to the Weedhopper however, further developments had occurred in the USA via competitor duplication, leading to the single seat Phantom produced by Phantom Aircraft of Kalamazoo, Michigan (Figure 5), which was later copied on two continents: firstly in Australia where with a change from swept to straight leading edge wing, and from nosegear to tailwheel configuration it became the Thruster, and with far less changes by Letov Air in what is now the Czech republic as the Letov Sluka.

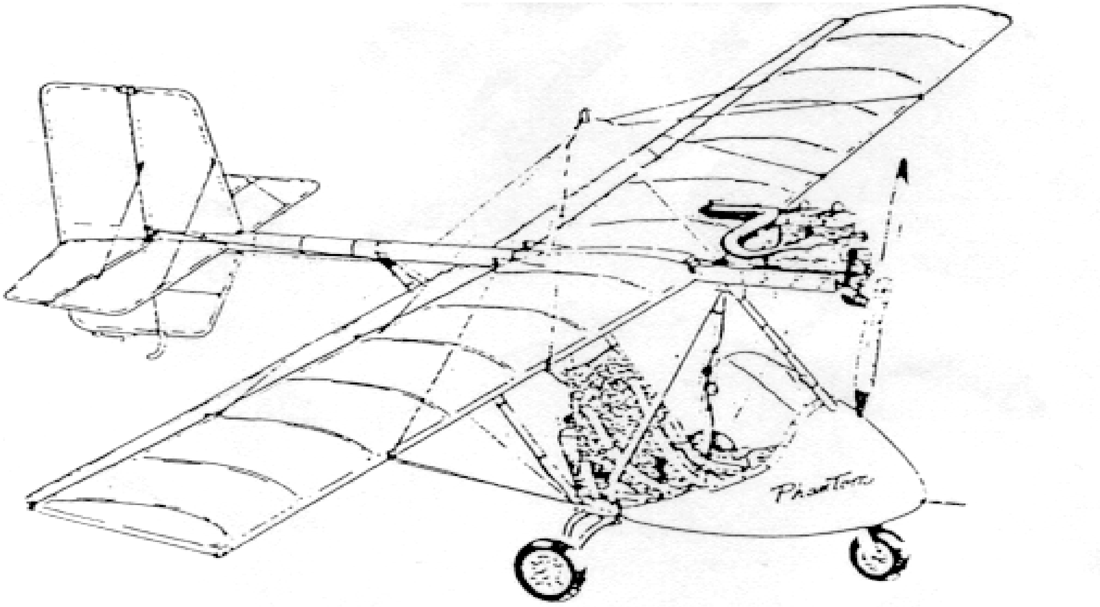

Figure 5 Phantom (courtesy of BMAA)

Figure 6 Letov Sluka (courtesy of Wikipedia Commons)

Globally, sales of both the Phantom and Sluka have been good; however, far more significant has been the development by Australian hang-glider designer Steve Cowan of the Thruster, which first flew in November 1982. In the early 1980s, the global 3-axis microlight market lacked a reliable 2-seat training aircraft. Training available in common light aeroplanes such as the C150 or PA28 families is very unrepresentative of these far lighter aeroplanes. This was solved by the introduction after several generations of development of the 2-seat Thruster TST Mk.1 (or Two Seat Trainer, known in Australia as the Gemini) about 1985, which despite being extremely crude, lacking doors, an internal engine starter or ground brakes, rapidly became a standard training aeroplane in the UK and Australia[6]. The Thruster TST had two seats and dual controls (a single stick between the seats, but duplicated throttles and rudder pedals). Performance allowed training from 250m semi-prepared runways, and it was cheap. These characteristics suited it well to this new training role.

Figure 6 Thruster TST Mk.1

Development of the Thruster marque continued in parallel in Australia and the UK, where an independent manufacturer had acquired design rights. Via a slightly modified Thruster T300 boasting a larger engine, higher MTOW and more streamlined structure, the Thruster T600 was developed (Figure 7), which became available in either nosegear or tailwheel variants.

Figure 7 Thruster T600T

To date the ultimate certified development of the Thruster marque has involved a fully enclosed cockpit and rear fuselage upon the T600, leading to the UK produced Thruster Sprint (Figure 8). An as yet uncertified development was a floatplane variant with retractable land undercarriage, of which a single example, G-INGE, is known to have been built.

Figure 8 Thruster T600N Sprint

A most recent, but slightly indirect evolution of the fuse-tube concept is the Ikarus C42, developed by German company COMCO IKARUS. Superficially, it is a very different aeroplane; however, if disassembled the aircraft retains the original Weedhopper concept of the fuse-tube mounting the engine and horizontal stabiliser; the wing is also substantially similar to that of the Thruster with straight leading and trailing edge tubes, and a fabric covering shaped with aluminium alloy battens. The primary differences are that the fuselage tube is now lower in the aeroplane – putting the powerplane and tail closer to the aircraft's vertical centre, and changing the attachments of the cockpit structure to the fuse-tube. The aerodynamic shape, like that of the Thruster Sprint consists of lightweight composite panels clipped to the structure and carrying no main load paths.

Figure 9 Ikarus C42

A further sideline development has been the designs of British aircraft designer Mike Whittaker, who originally designed a single seater with a nosewheel undercarriage and fully articulated cruciform tail – the MW4, which was developed into several variants of the MW5 which used a conventional rudder / elevator tail, and then in turn into two 2-seat variants; the tandem MW6T and side-by-side MW6S. In most cases amateur built from plans, these and a rare aerobatic single seat variant the MW7 exist in numerous variants.

Table 1 Performance of the most common fuse-tube aeroplanes

Aircraft Type	Vs (kn)	Vne (kn)	Sea level climb performance (fpm)	Installed power range (hp)	Typical fuel capacity (L)	Demonstrated crosswind limit (kn)	MTOW (kg)
Weedhopper JC24b	23	48	300	28-35	11-37	7	209
AX2	24	65	500	50	NK	NK	380
AX3	27	78	400	48-52	27	10	390
Cyclone AX2000	31	78	370 – 650	52 – 65	62	NK	
X’Air	33	83	625 – 1150	65-80	55 – 63	15	450
X’Air F	35	85	480 – 700	65-80	55 – 63	15	450
Thruster TST	35	80	500	48-52	25 – 38	None published, experience suggests about 8 knots	361-380
Thruster T300	32	80	450-600	52-65	25 – 39		380
Thruster T600N	35	80	400-630	52-80	25 – 39	15	390-450
Thruster Sprint	35	102	660	65-80	50	15	450
Ikarus C42	32	120	960-1020	80-100	50 – 100	15	450

Notes:

(1) Earlier microlight certification practices did not differentiate between IAS and CAS, so there is considerable uncertainty as to whether V_S and V_{NE} values for all but the X’Air, C42 and Thruster Sprint models show speeds in IAS or CAS.

(2) Mean fuel consumption of the 2-stroke engines used on most aircraft is typically around 0.25 litres/hr/installed-horsepower; for 4-stroke engines (T600 sprint, C42, some X’Air & AX2000 models) typically nearer 0.2 litres/hr/installed-horsepower.

(3) Cruise speeds are typically in the region of 60-70% of V_{NE}.

3. Test methods and flying qualities

The Weedhopper first appeared at a time where little or no formalisation existed in microlight flight testing; there was no formal certification process in any country, no test standards, no formal training or qualification of assessing pilots (nor in most cases, formal requirements for pilot training). From that era, a great many microlight and ultralight aeroplanes emerged, many of which were poor, and a few extremely dangerous. Only a small proportion of aeroplanes were well tested and documented, and fewer survived beyond the 1980s.

In Britain this changed with the introduction of BCAR Section S, the world's first formal airworthiness standards for microlight aeroplanes, which became fully mandatory for all new aeroplanes from 1984, and mandatory in part for "grandfathered" aeroplanes from 1987 through a process called Type Acceptance, administered by the British Microlight Aircraft Association. Type acceptance relaxed some of the less "core" aspects of design approval but normally required absolute compliance with flying qualities and structural minima. Shortly afterwards Germany was the second country to formally regulate microlight aeroplanes, with BFU-95, a derivative of Section S. It is interesting to note that the current European airworthiness standard for non-aerobatic light aeroplanes, CS.VLA [7], is via an intermediate document JAR-VLA [8], also a derivative of Section S.

In the United Kingdom, the imposition of formal regulations for microlight aeroplanes was the result of significant political and public pressure during the early 1980s. The first consideration was noise, because of public nuisance [9], leading to mandatory noise regulations in 1982 [10]. However, safety regulations followed rapidly behind, announced in a parliamentary debate in 1983 [11] and mandated from 1984. A philosophy of relatively "light touch" regulation was pursued and in particular microlight regulation was placed into the "technical officer" system for recreational aviation, where the implementation of regulation delegated substantially by the Civil Aviation Authority to one or more of the sport flying associations [12]. This model, pioneered with the Popular Flying Association and British Gliding Association immediately following the second world war, was later extended to the British Microlight Aircraft Association (formerly the British Minimum Aircraft Association) and the British Balloon and Airship Club, and proved successful, and continues now with the same organisations.

Type Acceptance flight testing of a former museum exhibit provided the first opportunity for formal investigation of the original Weedhopper – this was somewhat delayed but eventually completed at Kemble airfield in 2000. Perhaps surprisingly, the aircraft showed only one area in which the flying qualities minima were not comfortably exceeded – the point of bare compliance was that the climb rate was only just able to achieve 1000ft in 4 minutes at ISA sea-level – a characteristic which did not prevent certification but did force all flight testing to be carried out below an achievable ceiling of 3,000ft. The high dihedral effect combined with rudder-only airborne steering gave acceptable flying qualities but several unusual characteristics:

1. In even light turbulence the aeroplane displayed a continuous moderate amplitude neutral to lightly damped Dutch roll, which could not be readily removed but did not constitute more than a mild nuisance to the pilot.
2. Whilst in most conventional aeroplanes, the roll control (operating ailerons) provides a control which is essentially one of roll rate, i.e. that the roll rate is a function of stick position, in the Weedhopper the stick position defines the eventual steady state bank angle. So the pilot learned to select a lateral stick position which corresponded to desired bank angle and the aeroplane would roll to that bank angle, make some small but well damped rolling oscillations, and eventually stabilise. The aeroplane rolled wings level on centralisation of the stick. (This characteristic is common with the Pou du Ciel [Flying Flea] family such as the Mignet HM14 (Figure 10), which use a similar directional control mechanism.)

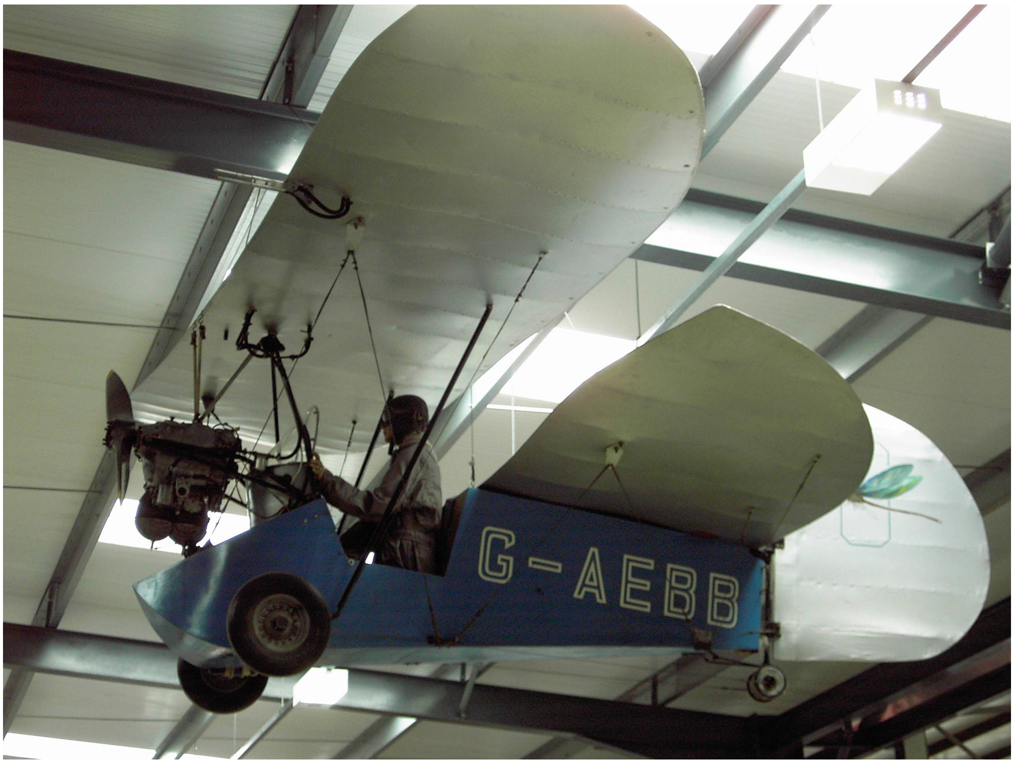

Figure 10, Mignet HM14 Pou du Ciel

3. The high dihedral effect, as is the case in some other aeroplanes with high lateral stability, was particularly noticeable in turning flight stalls (which were flown up to 30° of bank) where at the point of stall the aeroplane rolled naturally back to wings level.
4. The combination of a push-left-roll-left primary flight control and push-left-yaw-right ground nosewheel steering was very anti-intuitive but not in itself unacceptable in a grandfathered aeroplane (and the nosewheel steering mechanism is identical to that found in many weightshift controlled microlight aeroplanes). It was found that once centred onto the runway, pilots should fly the take-off by centralising the nosewheel steering pedals and steer the aeroplane entirely with the stick (rudder); this was easily flown particularly given excellent very low speed directional control power, whilst on landing the aeroplane should again be steered entirely using the stick with the nosewheel steering pedals centralised until after landing and the aeroplane was down to about 10kn when the stick should be held centrally and the aeroplane steered solely using the nosewheel steering. Combined use of nosewheel steering and rudder (stick), being in opposite senses, imposed unreasonable demands on the pilot and were strongly advised against.
5. The extremely low speeds of the aeroplane do not lend themselves to a conventional airspeed measurement system. The best solution was usually the crude, but reliable, Hall Windmeter, more normally found on sailboards (Figure 11).

Figure 11 Hall Windmeter

The next aeroplane in the evolutionary scale which was exposed to formal assessment was the AX3, tested for UK Type Approval in 1984. Type Approval was a newer process requiring full compliance with the certification basis, manufacturer approval and a degree of manufacturing oversight. This was the fifth 3-axis microlight aeroplane type formally certified in Britain and whilst (perhaps because) the community was still early on its certification learning curve, the process was reasonably straightforward. At this time, the practices in microlight flight testing were very much in their infancy, and based upon a "tick box" approach relating directly, and solely, to compliance with the cardinal points of the certification standard. Against this standard – which particularly was based heavily upon subpart B of wider known civil standards such as FAR-23 [13], although not including spinning, the aeroplane was found to be satisfactory.

For this aeroplane at-least, this rather shallow approach to certification seems to have been justified. In the UK, the AX3 rapidly replaced the Thruster TST in many flying schools as the preferred 2-seat training aeroplane and anecdotally the typical flying hours to first solo of student pilots routinely reduced from about 15 hours on the tailwheel Thruster to 10-12 on the nosegear AX3; the type, within the UK, has not had any fatal accidents in 28 years of service. Certainly the nosegear undercarriage, lack of flaps or any other "complex" controls beyond a pitch trimmer, single lever power control of the Rotax 2-stroke engine and positive static and dynamic stability in all three axes favour it as an aeroplane capable of allowing new pilots to fly safely in minimal hours – albeit pilots who may initially be only fitted to flying such a simple aeroplane.

The successor AX2000 aircraft was treated substantially the same, and in the variants using the Rotax 503 and 582 engines showed few significant differences – it was essentially a heavier and structurally strengthened variant on the same aeroplane, with very similar handling. Certified to BCAR Section S issue 1, spinning evaluation was still not required, and has probably never been done (nor however is there any record of an inadvertent spin in the type). Introduction of the lightweight 4-stroke HKS700E engine to the airframe brought some complications – the use of an airframe earthed Capacity Discharge Ignition (CDI) unit, which tended to destroy itself in the event of any failure of earth connection between anodised airframe components, was problematic and brought requirements for electrical interconnection of components not normally required of microlight aeroplanes; that and the relatively low power of the HKS engine (particularly for a 4-stroke aircraft engine) are probably the reason that it has not been widely adopted; certainly when it was fitted to the X'Air later the programme required significant flying hours and powerplant running adjustment to finally meet the already minimal certification requirement to achieve 1000ft in 4 minutes at MTOW / ISA sea-level conditions.

About 1998/1999 the United Kingdom enjoyed a step-change in the treatment of microlight aeroplanes. Eventual convergence with the European 450kg microlight definition was achieved with the release of BCAR Section S issue 2 [14]. This brought several significant changes to the certification of microlight aeroplanes: an increase in permissible MTOW from 390kg to 450kg for 2-seat aeroplanes, the ability to trade fuel for other payload, requirements for mandatory spinning assessment, and substantially more complex new undercarriage requirements. The first two are of course of greatest significance in the test programme, and in particular it was necessary to develop guidance on the spin testing of microlight aeroplanes. This was developed by BMAA in response to a tasking from the now disbanded UK Airworthiness Requirements Board (ARB), initially published at reference [15], and to date has not apparently required amendment.

The first aeroplane of any design to be assessed against these new requirements was the X'Air Mk.1, imported at that time for amateur construction by the Camelford and Wessex Light Aeroplane Company. This programme was managed jointly by the company, the BMAA, and by Flylight – a UK specialist microlight company who acted as a specialist flight test contractor in this role. The programme, as was often the case with prospective imports, commenced with an overseas quality evaluation assessment by the BMAA Technical Office in April 1998 – which identified that the aeroplane had potential for UK certification, then (in advance of the formal publication of Section S issue 2) the first UK prototype G-BYCL was built and a test programme commenced in January 1999 from Flylight's base at Sywell aerodrome near Northampton. Testing was intensive, and records show longitudinal stability testing in February, high speed and crosswind testing in March, then the programme completing with spinning tests in April leading to certification of the type for the UK shortly afterwards.

The type initially did show some significant deficiencies which required rectification, particularly in the direction of apparent longitudinal static stability – it was found that introduction of a wing jury strut to ensure compliance with an ultimate structural negative g minimum of -2.25g had constrained aeroelastic variable washout of the swept wing, and thus stick force per airspeed change could become as low as 0.03 daN / kn (in other words a total stick force change of about 1.5 daN (3.2lb) for the entire speed range of the aeroplane. Given that the aeroplane might reasonably be flown solo by student pilots with 10 flying hours, or qualified pilots with 15 – this was considered unacceptable. A solution was eventually found where the ailerons were reflexed – set permanently trailing edge-up, to give a low but acceptable absolute minimum stick force gradient of 0.1 daN / kn (0.22lb / kn) based upon tests with representative private pilots flown on board the UK prototype aeroplane. This worked, but created the interesting further consequence that because kit-aircraft are treated to some extent as "one-offs", all subsequent examples would require this to be evaluated during post-build flight testing, which in turn required pilots, who were not classically trained test pilots, carrying out flight testing of series aircraft to be trained in conducting manual longitudinal static stability testing (Figure 12).

#23.	50 kn, PLF, furthest aft CG attainable.	LSS Numerical check (this is essential for technical office to confirm that aileron reflex and pitch control are correctly set-up) A spring balance and tape-measure will be required.	CG: FoD* Trim Speed: IAS Force: Displacement: 30 40 50 60 70 * Forward of datum

Figure 12, Excerpt from X'Air Mk.1 UK series test schedule

Spin testing was also carried out from Sywell; the cramped cockpit and small door aperture making use of personal parachutes difficult and arguably not a reliable practice. The solution used was design of a whole aircraft parachute recovery system manufactured by BRS inc., similar to that more recently used in the Cirrus range of aircraft. The parachute system was mounted in the rear fuselage just aft of the seat-back fuel tanks, designed to fire sideways through an engineered frangible panel in the side fuselage. Twin looms were passed around both the main fuse-tube, and around the pilots harness attachment structure – on the basis that the parachute should be attached to the crew, regardless of what might be lost from the rest of the aeroplane. A parachute handle with a 2-part action was mounted from the cabin roof between the seats, configured so that to fire it needed to be rotated 90° then pulled to fire (the use of a double action being considered appropriate for safety), plus a conventional "pin safe" ground mechanism was used similar to an ejection seat. The configuration worked in that inertia ratios and external aerodynamic shape were essentially unchanged, whilst cockpit safety was maintained.

The actual spin characteristics (and it should be remembered that this was almost certainly the first formal spinning evaluation of any fuselage tube microlight) were called spinning primarily because no alternative term was available. A spin-like stalled rolling/yawing motion was experienced but with an extremely slow rate of 7-10 seconds per turn. Recovery was rapid (within one half turn without any particularly unpleasant motions) on control centralisation; because of this, a throttle-closed, controls (stick and rudder) centralised recovery was tested and approved rather than the light aeroplane's "standard stall recovery". This was justified on the following grounds:

1. It worked efficiently on every occasion
2. It did not require a pilot without any aerobatic training to identify the spin direction.
3. Evaluation of Standard Spin Recovery (using opposite rudder) showed some indications of the aeroplane attempting to switch to a spin in the opposite direction.

It is thought that the cruciform tail shape, combined with large fin of these aircraft (see Figure 3 above) probably was the reason why this controls-central recovery was so reliable; this recovery has come to be the preferred default recovery in microlight stall certification programmes.

The final iteration of the fuse-tube construction, to-date, has been the German designed Ikarus C42 (Figure 9), which has arguably been the least interesting from a flight test perspective. Some attempts were made to certify the aeroplane for deliberate spinning, although these were unsuccessful and the aeroplane is unique of the Weedhopper family in publishing a classical opposite-rudder spin recovery. Also with performance that comfortably exceeds equivalent light aeroplanes such as the Cessna 152 – this had, effectively become, and was flight tested as, a light aeroplane; recent regulatory changes have made routine fitment of a Ballistic Parachute, and raised the MTOW to 472.5kg (1042lb) to accommodate this. The aircraft has become a popular training and recreational aeroplane, and looks likely to remain so.

The (relatively) high performance nature however, highlights one other interesting point of certification of all light aeroplanes which is the requirement to maintain an acceptable margin between V_H (the maximum achievable speed in level flight) and V_{NE}, or more importantly V_D (the structural limiting speed). The simplistic requirement is that the aeroplane must not be able to get too close to safety limits whilst in level flight, and regulations have tended to define this by a margin of $V_D/V_H \geq 1.4$ for microlight aeroplanes, and $V_D/V_H \geq 1.25$ for light aeroplanes. In the majority of microlight and simpler light aeroplane programmes, V_D is defined by analysis, but then reduced to coincide with V_{DF} (the maximum speed at which handling was satisfactorily demonstrated in flight testing), and then V_{NE} is near-universally set at $0.9V_{DF}$. This really means that microlight aeroplanes must not be able to exceed 80% of V_{NE} in level flight – given the relatively high power / weight of some modern microlights (0.1 hp/lb at MTOW is not unusual), this has tended to be solved by fix-fly-fix adjustment of propeller pitch so that the requirement is only just met – the consequence being a relatively fine propeller pitch that gives quite impressive take-off and climb performance – for the highest performance C42 variant that is 205m (673ft) take-off distance to clear a 15m (50ft) screen height at MTOW in still air, and a 1020fpm sea-level climb rate. Few pilots have ever objected to short take-off distances and good climb rates, but a consequence of this has been that such aeroplanes have become routinely operated in the flying school environment, safely, often from grass runways shorter than 300m / 1000ft.

4. In Conclusion

This has been a historical paper about a family of aeroplanes that in about 25 years went from single seaters climbing at 250fpm and achieving 40 knots in level flight, to 2-seaters climbing at over 1000fpm and touching 90kn in level flight. Many, although certainly not all, of the aeroplanes have been both designed and tested by people without formal qualifications in aeronautics. They have been build in thousands, and continue to be flown in very large numbers.

The flight testing and certification history of the fuse-tube family of microlight aeroplanes has, to a large extent, been the story of how microlight aeroplanes have gone from crude uncertified – and often dangerous – machines, to properly certified and tested aeroplanes. This has involved some added cost and complexity, but they have not lost their accessibility and technical interest. There have been particular lessons learned; the ergonomic disaster of opposite sense ground and airborne steering controls, the Dutch Roll implications of a 2-axis controlled aeroplane, the knock on effects of inadvertently degrading handling qualities whilst trying to meet structural requirements (and determining what are acceptable characteristics for potentially very low hour and ability pilots), and the surprising advantage of creating excellent short-field capability as a result of ensuring that V_{NE} cannot be too-easily exceeded.

It is certain that the fuse-tube aeroplane will be with us for the foreseeable future – floatplane variants of the X'Air exist outside of the UK in less regulated countries including France and Portugal, and it is inevitable that there will be future attempts to introduce greater performance and complexity.

Acknowledgements

The author would like to acknowledge the collaboration in many test programmes of colleagues within the UK microlight test community, particularly Paul Dewhurst, Tom Porteous and Jon Viner.

Figures are the author's photographs except Figure 6, courtesy Wikipedia commons; Figure 5, courtesy BMAA; and Figure 12, from X'Air documentation.

The author

The author has conducted developmental and certification test flying, including several first flights, of multiple examples of each generation of aeroplane described in this paper, was from 1997-2005 Chief Technical Officer to the British Microlight Aircraft Association for whom remains a test pilot, as he also is for the UK's Light Aircraft Association.

He joined Brunel University in 2005 as a lecturer in aeronautics, where he set up the Flight Safety Laboratory. In 2008 he moved to Cranfield University to head the Facility for Airborne Atmospheric Measurements based there. However he has retained an oversight role for the Flight Safety work at Brunel.

References

1. Federal Aviation Regulations, Part 103: Ultralight vehicles Federal Aviation Administration, US Department of Transportation, Washington DC, 1982
2. http://www.weedhopperusa.net/
3. British Civil Airworthiness Requirements Section S Small Light Aeroplanes, CAP 482 working draft, UK Civil Aviation Authority, 1984
4. British Civil Airworthiness Requirements Section S Small Light Aeroplanes, CAP 482 issue 2, UK Civil Aviation Authority, 1999.
5. Homebuilt Aircraft Data Sheet for Raj Hamsa X'Air Mk.1, HADS HM1, British Microlight Aircraft Association, various issue states.
6. Anthony Woodward, *Propellerhead*, Harper Collins 2002 & 2010

7. European Aviation Safety Agency, Certification Specifications for Very Light Aeroplanes, CS.VLA to AL1 dated 5 March 2009.

8. Joint Aviation Authorities, Joint Airworthiness Requirements for Very Light Aeroplanes, JAR-VLA dated 26 April 1990

9. Hansard, Microlights, *HC Deb 21 July 1982 vol 28 cc379-80*

10. Air Navigation (Environmental Standards) Order 2002

11. Hansard, Microlight Aircraft, *HC Deb 26 January 1983 vol 35 cc429-30W*

12. GB Gratton, *A dispersed airworthiness management system – the model of the British Microlight Aircraft Association*, International Journal of Aerospace Management, Vol.1 No.4, pp329-335 (Feb 2002)

13. Federal Aviation Regulations, Part 23 Airworthiness standards: normal, utility, aerobatic and commuter category airplanes Federal Aviation Administration, US Department of Transportation, Washington DC

14. GB Gratton, *BCAR Section S issue 2, what is possible and a review of existing designs*, Proceedings of the 2000 Royal Aeronautical Society Light Aviation Conference "Design your own aeroplane", Cambridge Aug 2000

15. GB Gratton, *Guidance on spin testing microlight aircraft*, British Microlight Aircraft Association Technical Information Leaflet No. 025, Dec 1999