BCAR SECTION S ISSUE 2 - WHAT IS POSSIBLE ANDA REVIEW OF EXISTING DESIGNS.

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Introduction

British Civil Airworthiness Requirements Section S "Small Light Aeroplanes"**[1]** is a standard based upon the European light aircraft standard JAR-VLA**[2]**. It is an unusual standard in that it is a UK administered standard that is still in routine use and development, not having been superseded by a Joint Airworthiness Requirement (JAR).

Section S applies to the artificially defined class of "Microlight Aircraft" (some of which are also referred to as "SLAs"), Microlight aircraft are defined **[3]** as aeroplanes having no more than two seats, Vso not exceeding 35 knots CAS, and a maximum take-off mass of no more than:-

- 300 kg for a landplane, single seater; or
- 450 kg for a landplane, two-seater; or
- 330 kg for an amphibian or floatplane, single seater; or
- 495 kg for an amphibian or floatplane

(It should be noted that the amphibian part of the definition does not currently apply in the UK, although it is likely to from mid 2001. Also, the UK provides an alternative to the Vso requirement which is that the wing loading should not exceed 25 kg/m^2)

There are two other unusual elements to BCAR Section S. Firstly it is comparatively simple lacking many of the comparatively complex requirements of any of the JAA standards, or the older BCAR Section K **[4]**. Secondly it is a standard where the manner of proof is primarily assumed to be experimental rather than analytical. These two factors have led to an enormous amount of experimentation and innovation, probably far more than has occurred in any other class of aircraft design in the UK over the last 20 years. Because of this flexibility and simplicity however, the UK CAA considers the standard to only be suitable for issue of a *Permit to Fly* rather than the ICAO declared *Certificate of Airworthiness* standard.

Of approximately 3500 microlight aircraft in the UK, about 3100 are under the airworthiness supervision of the British Microlight Aircraft Association (BMAA), through delegation from the UK CAA (the remainder are controlled by the Popular Flying Association (PFA)). These aircraft fall into three categories: weightshift (also known as flexwing), 3-axis, and powered parachute (see figure 1 below). The three are flown on a single license **[5]**, but with separate type ratings.

Figure 1, Classes of microlight aircraft

Figure 1a, typical weightshift microlight (Mainair Blade)

Figure 1b, typical 3-axis microlight (CFM Shadow)

Figure 1c, typical powered parachute microlight (Buckeye)

It is the intention of this paper to describe the main sections of BCAR Section S, making comments upon the main issues and difficulties which are met during the certification process. Examples of existing designs will also be given.

Subpart A - General

Part A of BCAR Section S describes the definition of a microlight aeroplane, and also the range of non-aerobatic manoeuvres within which it is envisaged such an aeroplane may be operated. These are given as: -

- Any manoeuvre necessary for normal flying.
- Stalls
- Steep turns in which the angle of Bank does not exceed 60°.

It is worthy of note that this definition does not include deliberate spinning; however, spinning is a requirement of the certification process, just as it is with non-aerobatic light aircraft. Similarly turns beyond 60°, and particularly severe stalls which might not strictly be considered as non-aerobatic, are also routinely carried out during certification flight testing **[6, 7]**.

Subpart B - Flight

Flight characteristics are potentially even more important in the design of an aircraft than structural characteristics, since good handling qualities can usually prevent an aircraft ever reaching conditions where structural limits could be exceeded. Section S is, because of the comparatively low ability minima of microlight pilots, particularly strict in this regard. Below are discussed the most significant points of Section S's requirements.

CG Range and Weight Limits
It is not permitted, for any combination of permissible fuel loading and permissible seat loadings, for an aircraft to go out of CG limits. Whilst this obviously only applies to 3-axis aeroplanes (CG limits being largely unimportant in flexwing and PPC microlights) it is a very strict design parameter, and one which does not apply to any other class of aircraft. The range of loads per seat is not permitted to be narrower than 55kg to 86kg for the pilots seat, and zero to 86kg for the passenger seat. It is also specifically prohibited to make use of removable ballast to comply with this requirement - although some designers do use ballast to give a **preferred** CG position or wing loading, which is permissible**[8]**.

It is also a requirement that with 86kg in each seat, and 1hrs fuel at maximum continuous power, the aircraft cannot exceed MTOW. This requirement will normally determine the empty weight of an aircraft with a given powerplant; it also often prevents the certification in the UK of aircraft designed to the German Standard, BFU-95, which uses 70kg per seat and 30 minutes fuel.

Controllability, Manoeuvrability and Stability
Table 1 below shows the maximum permitted control forces in any aircraft axis. However, this is very firmly a maximum, and only in the most exceptional circumstances would a certification Engineer or test pilot be likely to accept control force values which come close to these values: -

Table 1 - Section S Maximum Control Forces

	Pitch daN	Roll daN	Yaw daN	Other controls daN
Temporary Application	20	10	40	10
Prolonged Application	2	1.5	10	---

Inevitably, control forces must be continuous and well harmonised. Roll rates must be adequate for the role of the aircraft (30° to 30° in no more than 5 seconds) without excessively high values of the Roll Mode Time Constant (τ_R). Apparent Longitudinal Static Stability must be continuously positive (although not necessarily linear) and there must also be no tendency for divergent short period oscillations, or for rudder over-balance. The aircraft also must be able to sustain a trimmed airspeed somewhere between 1.3Vs and 2.0Vs.

Manoeuvre Stability (referred to by the standard as "Pitch Control Force in Manoeuvres") is required for 3-axis controlled aircraft to not exceed 1.17 daN/g (7daN at a 6g proof load), with a similar (but less clearly defined) requirement for high control forces to reach proof loads in aircraft with other control systems. In the latter case, a specific value isn't given and acceptability is generally left to the approving test pilot / engineer. In practice the ergonomics of a weightshift aircraft (figure 1a) permit much higher forces without significant pilot discomfort, whilst the Shadow (figure 1b) with a short sidestick controller could not tolerate large control forces.

Stalls

Stalling characteristics must be reasonably benign (no more than 20° wing drop from a level stall, no more than 30° in-turn, or 60° out-turn wing drop from a 30° banked stall). Also, either the recovery from the stall must be easily achieved, or the aircraft must have a very clear stall warning mechanism (most commonly the former is the case and stall warning very weak). When considering stalling it should be mentioned that Section S only requires testing to be done at 1 kn/s deceleration rate, however because of the comparatively low inertia : drag ratio in this class of aircraft, certification testing always includes much more rapid stall entries**[6, 7]**.

Spinning

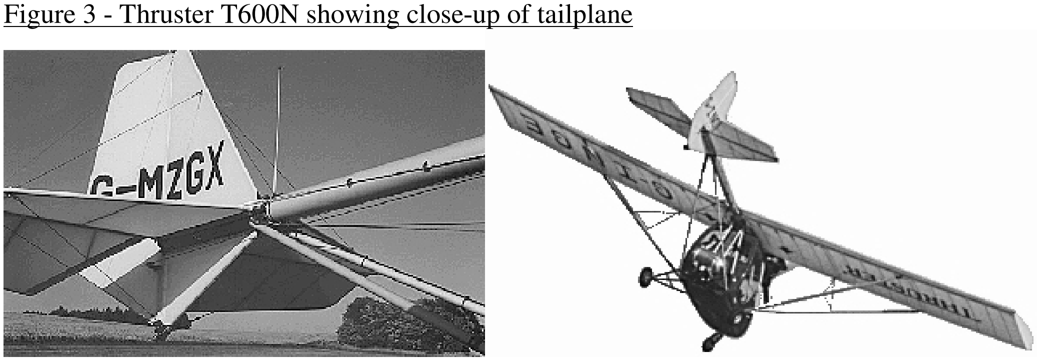
At issue 2, Section S introduced a requirement for a mandatory spinning evaluation of microlight aircraft before certification. This requirement is based upon that given in JAR-VLA**[2]**. The general requirement is that an aeroplane must be able to recover from a one turn or 3-second spin, whichever takes longer, in no longer than one additional turn. However the subject of spin testing is a complex and specialist task; guidelines on this subject are published in reference **[9]**, and some discussion of operational experience in this work is in reference **[10]**.

Because historically Section S didn't require spinning assessment to be carried out, some microlights did evolve with rather less than ideal spinning characteristics, probably the worst currently in use is the Aviasud Mistral (Figure 2 below), provides roll control from lower differential wing twist - meaning that the slightest lateral stick at the stall can potentially cause a spin. Also the rudder, largely blanked by the horizontal stabiliser doesn't end itself to a rapid recovery.

Figure 2 - Aviasud Mistral

By contrast, many microlights, such as the Thruster T600N in Figure 3 below have cruciform tails, lend themselves good low-speed control, spin resistance, and easy spin recovery. Unsurprisingly, the cruciform tail has found favour amongst designers in recent years.

Figure 3 - Thruster T600N showing close-up of tailplane

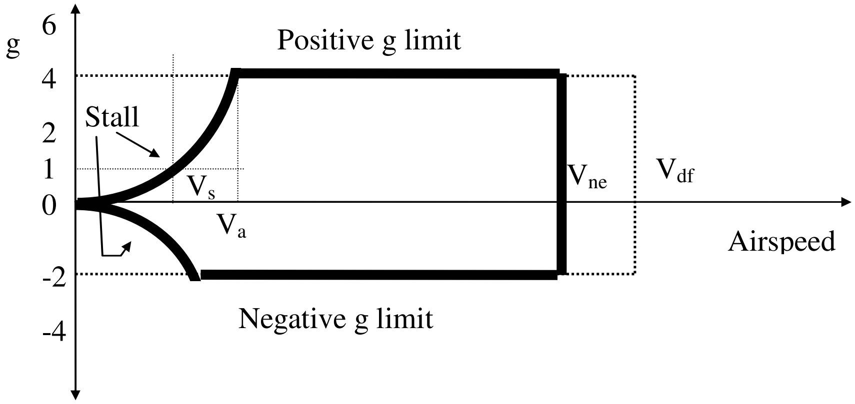


Subpart C - Structure

Main Flight Structure

Proof of the structural integrity of any aeroplane is essential to the approval process, and in a microlight no lesser requirement is applied. However, Section S provides a relatively simple set of requirements, which may be evaluated by testing rather than rigorous analysis - thus permitting comparatively inexpensive development of new structures and short lead times compared to the practice imposed by the manufacturing costs of larger aircraft. Virtually all microlight aircraft operate using the flight envelope shown in Figure 4 below. As in other classes of aircraft, whilst V_a is determined by normal force characteristics, all other flying controls must be proven to the greater of full deflection at V_a or $^1/_3$ deflection at V_d. V_{df} is the maximum safe speed achieved in flight testing, and never more than the design limit V_d. V_{ne} is usually (and may not exceed) $0.9V_{df}$. V_a may not exceed V_{df} / 1.4.

Figure 4 - Microlight V-N diagram



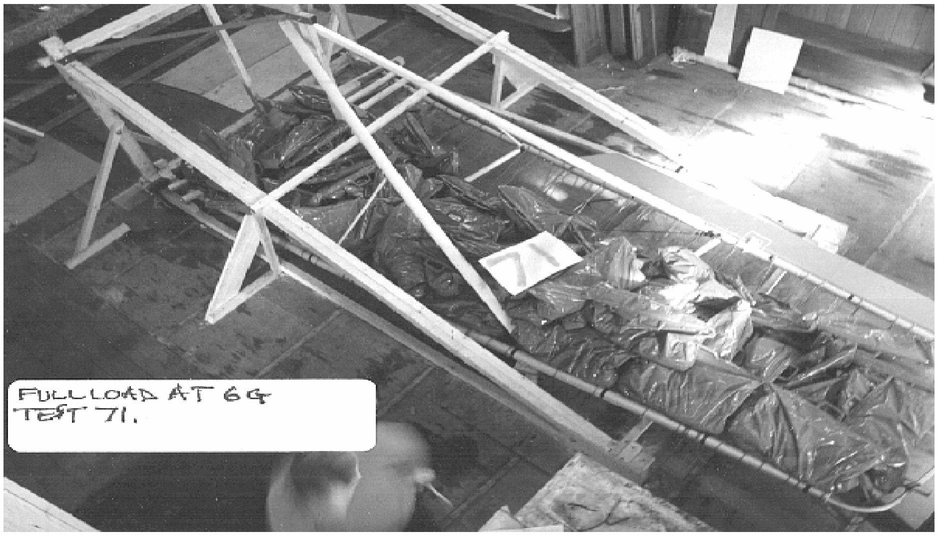
Although classical theory would place $V_a=2V_{S0}$ in the above diagram, occasionally this is not the case since some wings, particularly on weightshift aircraft, may not possess a linear C_L-AoA relationship, due to aeroelastic deformation of the lifting surface.

A proof factor of 1.5 is normally applied for conventional metal or wood structures, with a further factor of 1.5 (giving a total of 2.25) being applied to composite structures because of the relative difficulty in anticipating the residual strength of composites at the end of their service life. Where non-metallic flexible lines (such as the structural lines in a PPC microlight) are used, a 5.0 proof factor is applied. It is worthy of note that these extra factors for non-metallic materials often make metal the lightest design solution.

Vdf almost universally will not exceed 140 kn EAS because below this value there is within the standard only a limited requirement to consider gust and flutter cases (and thus the effort of certification is considerably less).

Whilst most designers will make use of analytical methods to confirm the viability of the structure, proof for certification purposes (and before flight testing commences) is virtually always carried out by physical load testing. The load distributions contained within Section S do not assume an aerodynamically likely elliptical load distribution, but instead apply a modified rectangular lift distribution. Whilst no Engineer would claim that this approach is aerodynamically valid, a simple consideration of the structural effects show that this approach is extremely conservative and thus in the safe sense. Also, it is an approach which lends itself particularly well to the loading of sandbags onto a wing! (See Figure 5 below)

Figure 5 - Load Testing of a Wing (Raj Hamsa X'Air Mainplane, 6g, sail removed)



Strength of control systems, which inevitably will be of the classic "reversible" type is also a significant issue in Section S, which uses values based upon the maximum likely pilot force (perhaps two pilots simultaneously trying to clear a control restriction); this is in contrast to many foreign microlight design codes which use maximum aerodynamic forces as the basis for control system strength. Table 2 below shows the minimum control strengths (at the inceptors) used in Section S for "conventional" 3-axis controls; for other control systems, forces are usually established by demonstration.

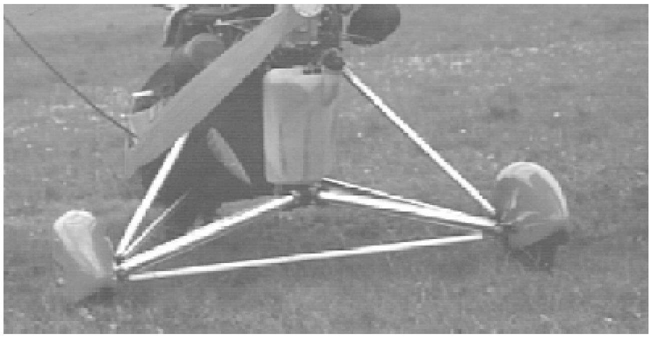
Table 2 - Minimum control system strengths (inceptor loads)

Control	**Minimum Force (daN)**	**Method of application**
Primary pitch	75	Handgrip on control column
Primary Roll	30	
Primary Yaw / other foot control	90	Pedal
Miscellaneous secondary controls	24	Handgrip on control lever
Small handwheels / cranks	15	Finger or wrist force
Misc levers and hand-wheels	35	Unsupported arm (no body weight)
Misc levers and hand-wheels	60	Supported arm, or applied body weight
Misc. pedals (e.g. toe-brakes)	75	Foot loads when pilot is sitting with back supported

Undercarriage

Historically Section S, at its original working draft and then at issue 1, required undercarriages to withstand static loads calculated as a factor of MTOW. This had the primary advantage of simplicity but was highly unrealistic. Beyond the obvious need to hold up a parked aircraft, an undercarriage is primarily a shock absorber. The undercarriage requirements of Section S at issue 2 reflect this, encouraging lighter and more energy absorbent landing gear than was previously the case (as a rule of thumb any undercarriage able to compress more than 40mm during the landing impact can probably be made lighter if designed to meet issue 2 than issue 1 of Section S). Figure 6 below shows a wing tested to the previous, force based requirement, and it can be seen that there is little shock absorption. The designer armed with Section S issue 2 should be able to give pilots far gentler landings.

Figure 6 - Mainair Gemini Undercarriage



The disadvantage of these newer requirements, particularly for the amateur designer, is that in order to determine maximum impact loads for an energy absorbent undercarriage, some higher mathematics (mainly integral calculus and simultaneous equation solving) is required than had previously been the case **[8]**.

Beyond these inevitable strength requirements, there are no specific limitations upon the type of undercarriage which can be used. However, designers should consider the minimum ability level of the pilots who may fly these aircraft. The 1990s saw a large number of ground handling accidents to a popular homebuilt light aircraft with an unusual undercarriage configuration; the familiar tricycle undercarriage may not always be the best design solution, but it is far less likely to suffer "pilot-error" landing accidents!

Other Items

Section S's structural section terminates with a series of "emergency landing" (crash!) conditions, which apply to much of the structure of the aircraft. Although they are very similar to the conditions found in any airworthiness standard with which the reader may be familiar, because they are so fundamental to aircraft design, even at the conceptual level, they are summarised in table 3 below.

Table 3 - Crash Conditions (minimum ultimate values)

Condition	**Minimum Requirements**
Occupants, ballast, engine, point masses (e.g. batteries), fuel tanks without spillage	4.5 upwards 9.0g forwards 3.0g sidewards 4.5g downwards
Occupants, gear-up landing case	3g downwards coefficient of friction with ground, 0.5
Engine - through cockpit or fuel tanks	15g

<u>Subpart D - Design and Construction, Subpart E - Powerplant, Subpart F Equipment</u>

Subparts D, E and F of Section S contain a great deal of useful and detailed advice, distilled from many decades of light aircraft design and operational experience. Because of the varied and detailed nature of this advice, there is little point in attempting to summarise it here and the reader is referred directly to the standard.

However, it is very useful to examine what is specifically not regulated by these sections, and the philosophy underlying this. This is fundamental to the freedom and flexibility particularly enjoyed by Engineers designing microlight aeroplanes. A microlight aeroplane is certified as a whole aircraft - there are no separately approved subsystems or materials - even the powerplant. This does not mean that certified engines, or aerospace certified materials are not regularly used (it is after-all usually easier to use a part that is already certified for aircraft use than one that is not) but this is neither mandatory nor usual practice. Below are considered the most significant implications of this.

Selection of Materials
It is not essential to use specifically “aircraft approved” materials, or materials suppliers for microlight aircraft construction. In practice fabrics, fasteners or instruments are routinely used which are not, and in all likelihood could not easily, be approved for use on an aircraft holding a Certificate of Airworthiness. Acceptability of materials or parts is normally established by the testing (usually to destruction) of representative samples or sub-structures - the reports from such testing becomes part of the certification reports for the aircraft.

Powerplant
There are many characteristics which would normally be considered mandatory in a light aircraft engine: certification, twin magneto ignition, twin plug ignition, etc. which although commonplace on the engines fitted to microlight aeroplanes, are not mandatory. Whilst normally the approving Engineer will require either operating experience on another aircraft, or significant (perhaps 100hrs) ground running before permitting a new engine to fly, in practice the only requirement of Section S is 25 flying hours under test conditions for any new (airframe : engine : gearbox : propeller) combination.

This permits generally extreme flexibility, and motorcycle engine adaptations or other experimentation are not unusual - so much so that a standard approval schedule exists for such purposes **[11]**. The relatively low cost of the uncertified instrumentation normally fitted to microlight aircraft also means that these installations are routinely more thoroughly instrumented than might be found on a light aircraft’s Lycoming installation (twin EGT, RPM, fuel pressure, engine hours, and either CHT or coolant temperature would be a typical combination on a modern microlight**[12]**).

However, there is an overriding consideration which falls outside of Section S but may often be the deciding factor in the acceptability of a powerplant - noise. Legislators in the UK **[13]** and in other countries are very aware that the low flight speeds of microlight aircraft create a noise nuisance beyond their pure dB output. In the UK, the limits are currently 76dBA (SEL) for a single seat microlight and 80dBA (SEL), for an aircraft flying level at 400ft agl with maximum continuous power selected, as measured on the ground. This has effectively prevented any experiments with jet engines (which are not strictly prohibited) and has also done a great deal to provoke the development of considerably quieter 2-stroke aircraft engines.

Unlike most other light aircraft or microlight standards **[2]**, Section S does not restrict the aircraft to a single engine. Whilst it is difficult to shoehorn more than one engine into such a low MTOW, it can be done. Probably the best known example is the AMF Lazair III (Figure 7) which uses two single cylinder Rotax 185 engines. The author believes that there is potential within Section S for more twin engined aircraft, although few designers have yet risen to this challenge.

Figure 7 - Lazair Microlight Aircraft

Flying Controls
Section S permits a great deal of innovation in the field of flying controls which, whilst not prohibited by other standards, is discouraged. Whilst any system must of-course be proven fit for flight, many approaches have been used with varying degrees of success. Table 4 below lists control systems which are used in microlight aircraft currently operating, with some examples. This is not intended to be an exhaustive list, it is a demonstration of what is possible.

Table 4 - Some Currently Used Control Systems

Control / axis	Method	Example Aircraft
Pitch	Elevator	Kolb Twinstar II
	All moving horizontal stabiliser	Whittaker MW6
	All moving tail	Whittaker MW4
	CG movement	Any flexwing
	Pitching of mainplane	HM1000 Ballerit
Roll	Ailerons	Rans S6
	Slotted spoilers + upgoing ailerons	Goldwing
	Front edge hinged ailerons	Snowbird IV
	Rudder + dihedral	Weedhopper JC24b
	CG movement	Any flexwing
	Differential wing twist	Aviasud Mistral
Yaw	Split tip-fins	Goldwing
	Conventional Rudder	Renegade Spirit
	No yaw control	Any flexwing
Pitch trim	Spring bias	Spectrum
	Trim Tab	X'Air
	Wing trailing edge deformation	Mainair Blade
	Hangpoint movement	Medway Raven

(Table 4 continued)

Throttle	Hand-lever	Pegasus AX2000
	Twist grip	Disabled modified Southdown Puma Sprint
	Thumb lever	Disabled modified Thruster TST
	Foot control	Any flexwing
Ground Steering	Differential Brakes	CFM Shadow
	Conventional nosewheel steering	Chevvron
	Reversed nosewheel steering	Any flexwing
	Tailwheel steering	Thruster T600T

Instruments
The minimum instruments required by Section S are an altimeter, airspeed indicator, and whatever instruments are required by the engine manufacturer (normally a tachometer and a selection of engine temperature gauges, depending upon the engine).

However, apart from an obvious requirement for a reasonably coherent pitot-static system (if one is used, often altimeters are vented to the cockpit and a venturi ASI used for simplicity), the specific requirements for instrumentation are very loose. This permits the designer to use uncertified or semi-experimental instruments from various sources (such as the Brauniger electronic panel shown in Figure 8 below). This often results in microlights sporting a range of engine and flight instruments which, despite the day VFR restriction on this class of aircraft, would put to shame many light aircraft. It is however important for the designer to take seriously such instrument fits, not from the point of view of certification, but of application **[12]**. There is no point in simply filling a cockpit with avionics without fully considering both need and useage. Figure 9 below shows a typical modern microlight cockpit, with a reasonable set of instruments, but not enough to intrude unnecessarily into the pilot's workloads.

Figure 8 - Brauniger combined electronic instrument panel

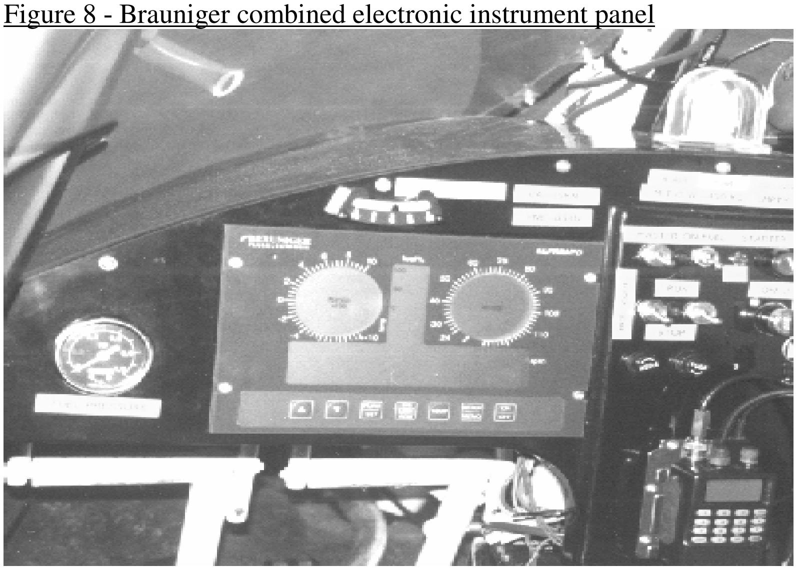
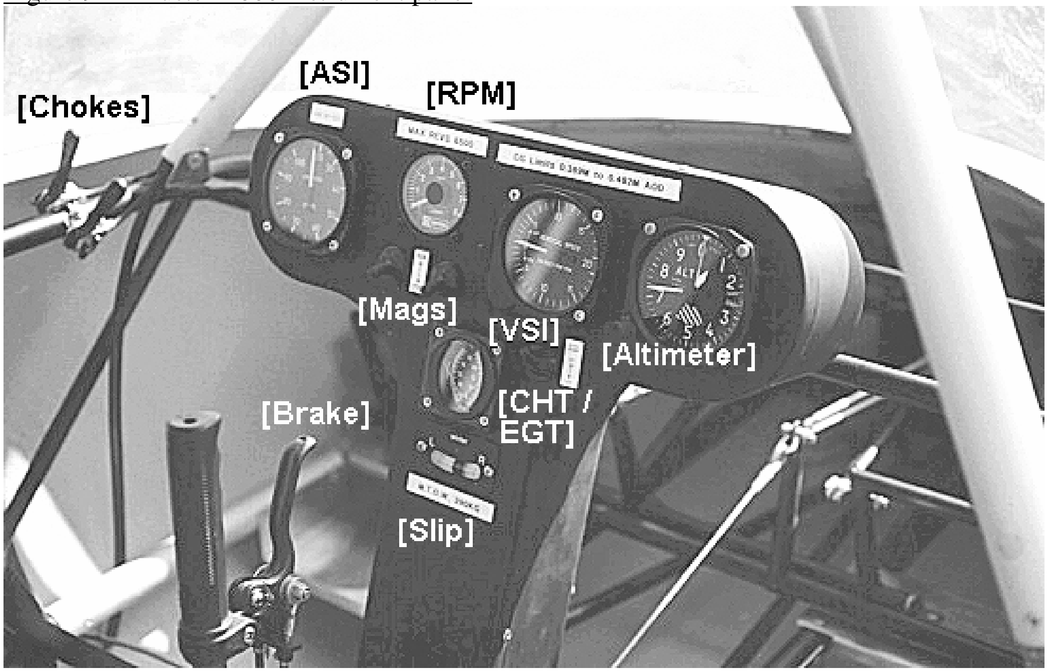


Figure 9 - Thruster T600 instrument panel



(Observant readers will note the lack of compass, this is on an overhead panel).

Subpart G - Operating Limitations and Information

Subpart G of Section S describes the operating advice which must be furnished with an aircraft. It is unfortunate, but many designers (particularly amateur designers) tend to regard this as something of an afterthought. However, from both a certification and an operational safety viewpoint, it is not appropriate to be too relaxed about these requirements.

It is vital that any aeroplane, including a microlight, is provided with a decent set of operating and maintenance manuals, and a safe set of flying limitations. It is inevitable that any sensible designer will make use wherever possible of existing standard documents are either include or “borrow from them”, examples being references **[14, 15]**, but even then this does tend to be regarded as an afterthought. Any microlight aeroplane must have before flight testing a draft Pilot’s Operating Handbook (POH) and maintenance manual, and before certification is achieved the designer, test pilot and certification engineer must be fully happy with a final version of this.

Similarly placards are essential to the safe operation of any aeroplane, even a one-off **[16]**. Section S gives very clear instructions on what is required and this is an area where certification Engineers at BMAA, PFA or CAA are notoriously unsympathetic to omissions or unclear instructions. However, designers should not regard this as a burden but an opportunity; good clear placarding, well thought out can be significant in both the efficient operation, and the aesthetic qualities of an aircraft. Placards and manuals should also be designed to co-ordinate with, not contradict, each other.

Subparts H - Engines, and J - Propellers.

Much is written elsewhere on the subject of engines and propellers **[17]**, and the author will politely decline to discuss the subject further here.

Subpart K - Microlight Parachute Recovery Systems

Whilst not an option commonly exercised, Section S permits the use of whole-aircraft recovery parachutes; it is the only civil standard available in the UK that does so. These operate in a similar manner to the classic Martin Baker ejection seat except that the whole aircraft, complete with occupants, is returned to earth under a parachute canopy. Readers considering the design of such an installation are referred directly to the standard, and to the interpretative notes published by the BMAA **[8]**. Figure 10 below shows a BRS unit (the parachute is inside the large cylinder, the rocket drogue inside the smaller) fitted to a Pegasus XL-Q aircraft.

Figure 10 - BRS recover parachute fitted beneath Pegasus trike

Conclusion

The author has attempted to demonstrate to the reader, presumed unfamiliar with microlight aircraft, the scope and primary issues concerned in microlight aircraft design using the guidelines of BCAR Section S. Examples have been given of particular aircraft with particular design solutions.

References

1 **British Civil Airworthiness Requirements**, Section S, Small Light Aeroplanes *CAP 482*
2 **Joint Aviation Authorities**, Joint Aviation Requirements - Very Light Aeroplanes.
3 **Joint Aviation Requirements,** 1.1 General Definitions
4 **British Civil Airworthiness Requirements**, Section K, Light Aeroplanes.
5 **British Microlight Aircraft Association,** Syllabus for the PPL(Microlights)
6 **British Microlight Aircraft Association**, Form BMAA/AW/010a, Flight Test Schedule for Section S compliance - 3 axis aircraft, Vd not exceeding 140 knots.
7 **British Microlight Aircraft Association,** Form BMAA/AW/010b, Flight Test Schedule for Section S compliance - flexwing aircraft, Vd not exceeding 140 knots.
8 **British Microlight Aircraft Association**, Current Interpretation of Section S, *Technical Information Leaflet 016*
9 **British Microlight Aircraft Association**, Guidance on Spin Testing Microlight Aircraft, *Technical Information Leaflet 025*
10 **Gratton G & Porteous T,** The creation of a formal test flying system within the British Microlight Aircraft Association and a discussion of the spin testing of microlight aircraft, *http://www.setp.org/microlightaircraft.htm*
11 **British Microlight Aircraft Association**, form BMAA/AW/040 (title?)
12 **British Microlight Aircraft Association**, Instrumentation and Avionics, *Technical Information Leaflet 027*
13 **British Civil Airworthiness Requirements**, Section N, Noise.
14 **British Microlight Aircraft Association**, Microlight Maintenance Schedule MMS1 issue 2, *Technical Information Leaflet 020*
15 **Bombardier Rotax**, Operators Manual Type 377, 447 and 503 engines
16 **Popular Flying Association,** Placards and Labels, *Information Letter 17*
17 **British Microlight Aircraft Association**, Propellers for microlight aircraft, *Technical Information Leaflet 011*

Note: Several BMAA documents are referenced above. These may be found at http://www.bmaa.org/tech2.htm Similarly, PFA documents can be requested from the PFA website at http://www.pfa.org.uk/