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# FREEBIRD GLIDER CONTROL

## MIKE BOYDEN

*An automatic flight attitude control system suitable for free flight model gliders*

I N order to amuse his young nephew last summer, the author made a number of model gliders, which were taken to the top of a local hill and then launched. The models were made from balsa wood and were not powered in any way, except by gravity.

Several designs showed some promise, but maintaining level flight with any consistency was a problem. Promising designs were shelved because after 20 metres they showed signs of losing stability, preferring to roll over or stall with the occasional "crump" of deforming balsa wood.

### FLIGHT TIMES

As their glides were observed, it seemed apparent that it must be possible to incorporate an automated flight control system, to give the designs at least a fighting chance. Following a number of prototypes, this article describes how to make and install into a model glider a low cost microcontrolled stabilisation system that helps model gliders to fly a little more straight and level.

Glider flight times have been increased from an average of five to six seconds to over 15 seconds – the limitation now being that the author's local hill is just not big enough! The real power of Freebird is that the flight correction algorithm can be modified by re-programming the PIC16F84A microcontroller, which handles the attitude detection and flight correction, all in real time.

### FLIGHT PATH

To encourage budding aeronautical engineers (young and old) to take up this mid-summer madness, an overview of aircraft flight dynamics and some practical flying information has also been included. The design has been kept simple, using low cost and readily available components. For inexperienced model makers, a glider can be purchased.

During development, a portable computer was used in conjunction with the *EPE Toolkit Mk3* (Oct/Nov '01), to provide full "in-the-field" tuning of the software, but this is not essential.

### FLIGHT THEORY

A full analysis of how aircraft fly is a complicated subject and cannot be fully detailed here. Further reading on the subject of aerodynamics is given at the end of this article.

In summary, for a fixed wing aircraft to fly, it must be made to move forward. The wings are designed to convert part of the falling motion into a forward motion. As the wings move forward they produce lift, which acts against the weight of the glider, effectively making it "lighter". The "lighter" glider in turn requires less forward speed so it settles into stable forward flight.

The forces acting on a glider in stable flight are shown in Fig.1. The main forces are:

● Lift force generated by the wings (upwards)

● Weight of the glider and control electronics (downwards)

● Drag or retardation force as the glider tries to move through the air (backwards)

● Propulsive force which for gliders is supplied by gravity (forwards).

In stable flight, the lift force is just less than the weight force, (i.e. the model slowly descends) and the thrust force is greater than the drag force (i.e. the model moves slowly forward).

The objective of glider designers is to maximise the distance moved forward by the glider and minimise the vertical distance it falls. This is known as the optimal glide-slope (refer to Fig.2) and Freebird is aiming to keep the glider within these operating parameters at all times.

Incidentally, this is also a guide to the slope of a good hill to launch from, as the glider should be able to continually "fall", yet maintain a constant height from the ground.

So by the addition of wings, the simple falling object is turned into a gliding object. The next problem to solve is how to control the motion of the aircraft in three-dimensional space.

## FLIGHT CONTROL

Aircraft travelling in space can move in the following ways (see Fig.3.):

● Pitch – a rotation about an axis that passes through the wings – looks like a raising or lowering of the nose. To correct alterations in pitch, the elevators located on the tail surfaces are adjusted in unison (i.e. both elevators up or both down).

● Roll – a rotation through the centre line of the fuselage – looks like one wing rises, whilst the other falls. To correct alterations in roll, the ailerons located on the wings are adjusted in opposition (i.e. one aileron moves up, whilst the other moves down).

● Yaw – a rotation about an axis perpendicular to the fuselage. To correct alterations in yaw, the rudder located on the tail is adjusted.

When in flight, all sorts of forces act on the aircraft, so that at a given instant any combination of these motions may be evident – it really is a wonder that a hand thrown model glider flies any distance at all! So, the idea behind Freebird is to correct these motions before they become too extreme and result in the aircraft crashing.

● A computational system that detects attitude alterations and determines the correction necessary to restore normal flight.

● A servo system, that can move aircraft control surfaces as directed by the attitude computer.

Usually, computations are based upon "generic" information that forms the basis of an in-flight mathematical model for that particular type of aircraft. Also, specific information is added that relates to that flight i.e. aircraft weight and local weather conditions.

Freebird does not carry out any mathematical computations, but outputs a pre-defined value of servo correction from look-up tables. Commercial detection systems make use of sophisticated detectors, including detectors sensitive to acceleration, which results in more refined control.

Although Freebird does not offer the sophistication of commercial systems, it does incorporate all of the elements detailed above.

correction for this motion is derived from the measurements taken from the pitch and roll sensors.

To assist the setting up procedure, light emitting diodes (l.e.d.s), D1 to D4, are included in series with the tilt switch, and are turned on when the respective switch closes. This corresponds to about 10 degrees of tilt.

Switches S5 to S8 are slide switches within a 4-way dual-in-line (d.i.l.) module. They allow different software routines or modes to be selected, as discussed presently, thereby altering the correction characteristics of Freebird.

The software can be changed without the removal of the PIC from the unit, by means of "in-circuit" programming socket, SK1. Note that this does not correspond to the pin arrangements used by John Becker in his numerous *EPE* projects.
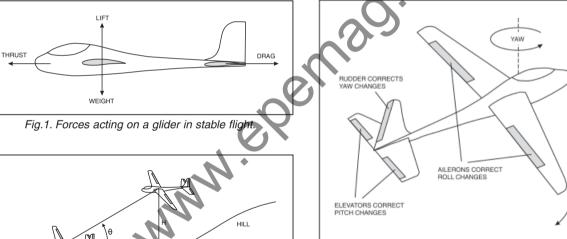


Fig.1. Forces acting on a glider in stable flight.



$$\text{GLIDE SLOPE } \theta = \text{TAN} \frac{H}{L} \approx 6° \text{ TO } 10°$$

Fig.2. Optimum glide-slope. Objective is to maximise distance moved forward and minimise the vertical distance it falls.



Fig.3. Aircraft attitude and surfaces used to control movement. These help stabilise against the forces of pitch, roll and yaw.

## FREEBIRD DESIGN

The design for Freebird was loosely based upon commercial aircraft autopilot systems. Auto-pilots allow pilots to relax by flying the aircraft without any human intervention and are normally used in the mid-section of long flights where airspace is not crowded and there is less need for the aircrew to laboriously maintain a fixed heading and level flight.

Any autopilot requires the following systems to be present:

● An attitude detection system.

## CIRCUIT DESCRIPTION

The complete circuit diagram for Freebird is shown in Fig.4. The heart of the system is the PIC16F84A microcontroller, running at 20MHz, as set by crystal X1. Tilt switches sense changes in pitch (S1, S2) and roll (S3, S4). They are arranged in the same plane, but offset with each other at 90 degrees (see Fig.5).

When perfectly level, the switches are arranged to be off, which gives a degree of "dead band" and helps to reduce the sensitivity of the detection system. There is no sensor present to detect yaw and the

## FEEDBACK COMPUTATION

The software assembly listing contains a full description of the PIC's program operation and other details, so just a short summary is given here. The PIC undertakes the following tasks:

1. Reads the mode switch and executes the appropriate software module

2. Detects pitch or roll tilt, by means of the tilt switches (active low)

3. Determines the appropriate servo(s) to move and by how much

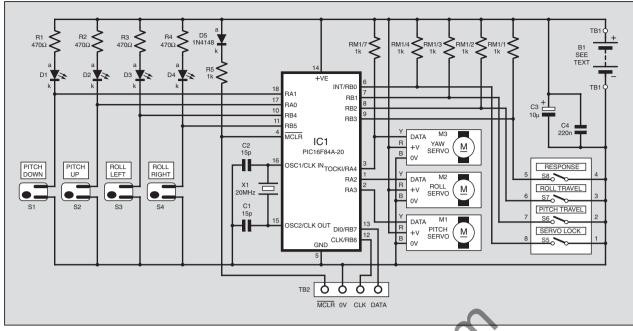4. Determines if yaw correction is required based upon roll and pitch

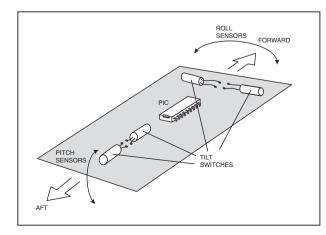*Fig.4. Complete circuit diagram for the Freebird Glider Control.*

5. Outputs corrective commands to the roll, pitch and yaw servos

The main activities are carried out in (1) to (4) and are arranged to loop endlessly. The servo output module is called by a timer interrupt every 18ms and this ensures that the servos receive their control information, irrespective of other activities going on at the time.

The main loop senses which, if any, of the tilt switches are active. The combination of tilt switch closures is used to enter look-up tables which define the appropriate degree of servo correction necessary. These values are placed into servo position register stores in readiness for output when the servo interrupt is executed.

The following modes are available in the software, and are selected by switches S5 to S8:

| S5 | S6 | S7 | S8 |
|---|---|---|---|
| Servo Lock | Servo Travel Pitch | Servo Travel Roll | Response |
| On enabled | full | full | fast |
| Off disabled | half | half | slow |

Servo Lock, switch S5: When enabled, all servos are locked in their current positions. This helps with alignment (say, checking zero, maximum up or down elevator deflection on the aircraft). It also allows the initial checking of l.e.d.s to be carried out in comparative quiet without the servos moving.

Servo Travel Pitch, switch S6: the travel of the pitch servo can be increased or decreased. When enabled, the servo rotation is ±60 degrees. When disabled the travel in each direction is halved, i.e. about ±30 degrees.

Servo Travel Roll, switch S7: as Pitch switch S6, but with respect to the roll servo.

Response, switch S8: when enabled (slow), the rate of travel of the servo movement is approximately one second from +60 degrees to 0 degrees. This sluggish response is better for flying on still, hot summer days, or with larger gliders. When disabled (fast), the movement is speeded up to 0·5 seconds. This setting is useful in gusty conditions where the glider must respond rapidly in order to maintain stability.

Any mixture of the above functions can be selected.



*Fig.5. Attitude detection using tilt switches. Pitch S1/S2 and roll S3/S4 are arranged in the same plane, but offset at 90° from each group*

## POWER SUPPLY

A supply of between about 5V and 6V is required to power the PIC and servos. Power consumption peaks at around 430mA with all three servos in motion, but normal steady state consumption is around 45mA. To keep costs down, dry cells can be used although rechargeable cells such as Nickel Cadmium do help to reduce costs in the long run.

The most important consideration here is weight. Use of four AA-size batteries is acceptable, weighing about 170 grams, and supplying about 1·5V each (total 6V). The balance of the glider is important and the battery pack will play an important part in the eventual setting up.

## SERVOS

Model radio control servos are used to control the aircraft as these are purpose built, lightweight, available at modest prices and are designed to be installed into model aircraft. Radio control servos require a position instruction every 18ms and the PIC's interrupt routine is set to output this information, irrespective of what other tasks are being executed. The servo position instruction comprises a 1ms start pulse followed by a command pulse varying between zero and 1ms.

The servos are 3-wire units. The positive lead connects to the power supply positive line, the earth connects to battery negative, and the data line to the appropriate PIC output.

An analysis was not considered necessary with regard to the vulnerability of each system to the overall stability (and therefore safety) of the control system as it would be used in a hobbyist setting and not for commercial use.

However, an airbrake could be added should the glider remain airborne for too long. Readers knowledgeable in PIC program writing could easily modify the software to drive another servo to control
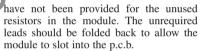


*Completed printed circuit board connected to a single servo motor. Note the four attitude tilt switches.*

it. A timer of up to 14 minutes duration could be created by counting the 18ms interrupts by means of a 16-bit counter.

## CONSTRUCTION

The printed circuit board (p.c.b.) assembly and track layout details are shown in Fig.6. This board is available from the *EPE PCB Service*, code 367. Assemble in your own preferred order, noting the direction of the diodes and capacitor C3. Use a socket for the PIC.

Identify the common lead (it has a spot alongside) on the s.i.l. resistor module and position it as shown. Note that p.c.b. holes

have not been provided for the unused resistors in the module. The unrequired leads should be folded back to allow the module to slot into the p.c.b.

Install the tilt switches with plenty of curvature in the leads – this will make later adjustments easier.

Make sure the d.i.l. switch is soldered in correctly (i.e. the switch should be closed when at the top of the bank, and off at the bottom).

After you have fully checked the correctness of your soldering and assembly, and confirmed that the power supply is correctly working, insert the preprogrammed PIC into its socket, ensuring its correct orientation. If you have your own PIC programming facility, such as the *EPE Toolkit MK3/TK3* programmer, the PIC could be programmed *in situ*. See this month's *Shoptalk* page for details of obtaining the software and preprogrammed PICs.

Note that the programming pinouts of the TB1 connector do not correspond to the "standard" John Becker arrangement.

Do not connect the servos to the p.c.b. until after the following initial setting up.

## SETTING UP

Place the assembled p.c.b. on a flat table and ensure that switch S5 (Servo Lock) is selected to *disabled* (i.e. all servos unlocked). Physically adjust the vertical angle of the tilt switches until all the l.e.d.s are just out. Raise the free end of the bent over tilt switch to turn it on earlier, lower to turn it off later.

To check the Pitch setting, raise the rear of the board by approximately 10mm until tilt switch S1 and l.e.d. D1 just turn on. Return
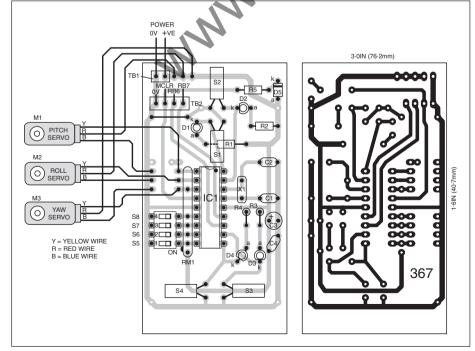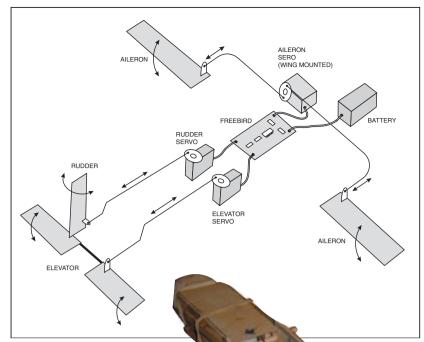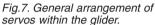


*Fig.6. Freebird printed circuit board component layout, wiring details to servo motors and full-size copper foil underside master pattern.*

Fig.7. General arrangement of servos within the glider.

the board to horizontal and then raise its front by about 10mm, to check switch S2 and l.e.d. D2.

To check the Roll setting, lift the left edge of the board (i.e. bank to the right) and check tilt switch S4 until l.e.d. D4 just lights. Repeat for left banking.

Connect up the yaw servo. Check that this servo responds to right and left roll. Then connect up the Pitch and Roll servos (omit the roll servo if desired – see later). Mark each servo with labels stating "Elevator" (pitch, RA2), "Aileron" (roll, RA3) and "Rudder" (yaw, RA4). Check that all of the mode slide switches (S5 to S8) operate correctly.

Freebird is now ready for installation into a glider.

## WINGS AND THINGS

More experienced model makers may wish to build their own glider specifically for the job. For those new to flying "free flight" model gliders, purchasing a partially completed model is recommended, which only requires minor additions for completion.

For the novice, the subject of model gliders and how to fly them is quite extensive, but with a little patience, an enquiring mind and a will to "tinker", there is no reason why a reasonably good glider, with adequate flight characteristics cannot be built. Joining a club will be of great benefit to the novice.

With the prototype installation, using a NiCad battery pack and three servos, the weights were as follows:

| | |
|---|---|
| Battery pack | 150gms |
| Freebird p.c.b. | 30gms |
| Servos | 150gms (total) |

Adding a little for linkages, nuts and bolts, the total payload weight was about 350gms. The servos used for initial tests were far heavier than necessary and were later replaced with "micro servos", reducing the weight by 80gms.

The glider requires to not only lift itself, but also the payload, plus a little for luck. It all gets a little complicated now and you are best advised to ask your local model hobby store to recommend a glider. Tell them you need something suitable for a novice to build, the payload will be 350gms, with a low wing loading.

For good stability, look to acquire a glider with a "double dihedral" wing.

Fix the wings to the fuselage using several large overlapping rubber bands. This helps to absorb the shock when landing on a wing, which is a common event, although it is reduced as Freebird becomes more "tuned".

## ON BALANCE

The model must balance correctly in the pitch and roll axes. The balance point for pitch should be one-quarter to one-third of the width of the wing back from the leading edge. Position batteries or a dummy weight to obtain this balance point.

Check that the model balances also in the roll axis, by supporting each end of the fuselage centre line with pins. Check to see which direction the glider rolls. Use PVC tape or some coats of dope (model paint) on one wing as counterweights to correct as much as possible, although perfect balance in this axis is not really possible.

Note that Freebird is not sophisticated enough to enable a poorly constructed and set-up glider to fly, but it will extend the flight of a reasonably well set-up glider.

When selecting a glider, remember to check that the wings are detachable and that all the various parts will go through a car door. Access to the p.c.b. will be necessary to allow different software modules to be selected via the d.i.l. switch. This normally will require the wings to be taken off. If you intend to carry out "in the field" programming, check that a small hole can be made in the fuselage for the programming connector.

The first objective should be to obtain a good understanding of a free flight glider by making a series of flights with the glider loaded up with equivalent weight of batteries and servos. Learn how to note the weather conditions, how to check the balance, and how to launch.

Finally, learn how to note each flight and the correction(s) (make only one at a time) necessary to slowly improve the flight time. Breakages and how to fix them on the hills will become second nature!

## INSTALLATION

The flight of the glider is corrected by means of a moving rudder, ailerons and elevators in exactly the same way that full size aircraft are controlled, see Fig.7. The servos connect to the control surfaces by means of thin "push rods" or Bowden cable – most good model shops will stock such items.

The direction of travel of the servos is important to note, but more on that later. With the battery installed in the nose of the glider, the servos are all mounted in the fuselage, usually somewhere under the wing so that the glider balances, when held by the wing tips.

The aileron servo is mounted in the wing and this can be a little tricky for those new to model glider construction. The servo linkages should be arranged to deflect each aileron in the opposite direction (i.e. left up, right down), but they should both return to neutral. To ease this problem, it is possible to fly

Positioning of the circuit board, servos and battery (nose cone) in the fuselage sections.

Freebird using only two servos (elevator and rudder) although correction of roll is not as effective.

Each control surface will require a different degree of movement to adjust the flight of the glider, but a surprisingly small change can have a significant effect. Normally, the control surface needs to only move about 10 degrees above or below the horizontal to have an effect on flight attitude.

The surface area of the control and the speed of flight also have an impact upon the amount of travel necessary. Make use of the servo lock mode to view the travel distances and check the neutral point of each surface is exactly in the centre of travel. Add small offsets in the lookup tables to correct minor errors, or adjust the travel at

the servo arm. Also, most servo arms can be removed and repositioned to extend the range of convenient positions.

## SERVO TRAVEL

Note the direction of travel of each servo and check that the movement will alter the control surface in the correct direction. If the direction of travel is incorrect, swap to the other side of the servo control arm, or rotate the servo 180 degrees in the aircraft, or change the linkage to the control surface. Ensure that all of the movements are correct, before installing the servos, as making changes after installation in the glider is difficult and time wasting.

Ensure that some adjustment can be made to the servo travel (normally done with a small brass threaded screw connected to the servo drive disc, again available from model shops). If a PIC programmer is available then simply adjust the zero point in the "look-up" table.

Position the battery unit into the front of the glider. The glider should balance when held by the wing one-third of the way from the leading edge – check this and adjust the battery pack as necessary. Locate the battery pack with balsa wood and sponge to act as a shock absorber.

Connect up push rods or cables to the control surfaces. Install the p.c.b. (tilt switch S2 points aft (tail)) in the fuselage, under the wings and on the floor of the glider. Check that access to the programming socket is clear. Check that with the wings level and the fuselage level all l.e.d.s are off – readjust as necessary. If the servos are moving all the time, then they can be locked using slide switch S5.

Locate and bolt the p.c.b. into the glider and use a hot-melt gun to finally fix the tilt switches onto the PCB. It may be necessary to hot-glue any connectors, as the author has sometimes found them disconnected after forceful landings.

## SOFTWARE TECHNICALITIES

The software is written with simplicity and the expectation is that it will prompt experimentation, modification and improvement.

The core of the software is centred around the PIC TMR0 timer. This is set to interrupt the mainline every 13ms thus ensuring that the servos are serviced with their control pulses irrespective of the other things going on. The interrupt code outputs to each servo a 1ms start pulse followed a command pulse of between 1ms and 2ms duration.

When the program is not executing an interrupt, it is constrained to constantly execute the mainline loop. The mainline undertakes three tasks:

1. read mode switches and execute the appropriate software module

2. read tilt switches

3. calculate required position of all servos and load the demand variable, in readiness for the interrupt to output it.

Three variables define servo demand:

**servop** – pitch servo position

**servor** – roll servo position

**servoy** – yaw servo position

### Flight correction table for Pitch:

| Flight Attitude | Sensor values D1 | U1 | corrective servop value | elevator degrees |
|---|---|---|---|---|
| Level flight | 1 | 1 | 125 | 0 |
| 10 deg pitch down | 1 | 0 | 187 | 10 up elevator |
| 10 deg pitch up | 0 | 1 | 62 | 5 down elevator |
| Inverted flight | 0 | 0 | n/a | n/a |

### Flight correction table for Roll:

| Flight Attitude | Sensor Values L1 | R1 | Corrective servop value | Aileron degrees |
|---|---|---|---|---|
| Level flight | 1 | 1 | 125 | 0 |
| 10° roll left | 1 | 0 | 187 | 5 right aileron |
| 10° roll right | 0 | 1 | 62 | −5 left aileron |
| Inverted flight | 0 | 0 | n/a | 0 n/a |

### Flight correction table for Yaw:

| Flight Attitude | L1 | D1 | R1 | U1 | Corrective servoy value | Rudder degrees |
|---|---|---|---|---|---|---|
| level flight | 1 | 1 | 1 | 1 | 125 | 0 centre |
| 10° roll left, only | 0 | 1 | 1 | 1 | 187 | 15 right |
| 10° roll right, only | 1 | 1 | 0 | 1 | 62 | −15 left |
| 10° roll left, pitch down | 0 | 0 | 1 | 1 | 250 | 30 right |
| 10° roll right, pitch down | 1 | 0 | 0 | 1 | 0 | −30 left |
| 10° roll left, pitch up | 0 | 1 | 1 | 0 | 187 | 15 right |
| 10° roll right, pitch up | 1 | 1 | 0 | 0 | 12 | −15 left |
| Inverted flight | 0 | 0 | 0 | 0 | 125 | 0 centre |
| Error | 1 | 1 | 0 | 0 | 125 | 0 |
| Error | 0 | 0 | 1 | 1 | 125 | 0 |

A servo position is determined by the value placed in any of the variables above. Five positions for the pitch servo are given below. The current servo position is held in the variable **servpc** and is used where a slower rate of movement has been selected.

| Servop (decimal) | Servo degrees |
|---|---|
| 0 | −30 |
| 65 | −15 |
| 125 | 0 |
| 187 | +15 |
| 250 | +30 |

The rate of travel of the servos can be adjusted by means of the mode switch. The demand position is subtracted from the current position to give an error value and the servo is instructed to move in the direction so as to reduce the error to zero.

Freebird can operate a fourth (auxiliary) servo. This could be used to operate air brakes, after a period of time for example. As said earlier, one way to devise a timer could be to use the 18ms interrupt to increment a 16-bit counter. This would give timed periods in excess of 15 minutes.

It is possible for Freebird to detect inverted flight, but correction of this extreme situation has not been implemented.

New and experimental code can be programmed into the PIC either at home, or on the hillside and then tried out. The mode switches can be reprogrammed for this task if required.

The attitude sensors are defined as:

Pitch:
U1  forward sensor (senses 10° pitch up)
D1  aft sensor (senses 10° pitch down)

Roll:
L1  right sensor (senses 10° roll left)
R1  left sensor (senses 10° roll right)

Yaw:
not present (computed response)

## FLYING

Take care when selecting the launch site. Avoid crowded areas and places where the glider might stray into traffic. Make sure that access to the site has been approved and preferably fly with a club. The following list of equipment that can be put into a rucksack may be useful for the independent flyer.

Notepad and pen
Small selection of Balsa and glue
Tissue paper, dope, cleaner and brush (for covering holes in the tissue covering)
Selection of trimming weights (nuts and bolts)
Spare set of batteries
Pliers, screwdriver
Rubber-bands
PVC Duct Tape
Sunglasses, blanket, sandwiches, flask of coffee!

Choose a sight with a 180 degree unobstructed field of view (i.e. no trees, styles or fences etc) combined with a good slope of about 30 or 40 per cent. For initial glide testing, try to find a field with long grass – this makes a good cushion.

For the first flight, unlock the servos and set pitch and roll to maximum travel and response rate to fast. Tilt the glider and check that each control surface moves in the correct direction. Recheck the glider balance, under the wing tips.

Launch the glider into wind whenever possible. Try to avoid gusty conditions at first. Do not launch the glider upwards – this will result in a stall. What the glider initially requires is airspeed, so launch the glider horizontally. It will initially drop quickly until airspeed is gained and then it will then slow down and settle into stable flight.

As soon as possible note what the glider does. If it pitches up and stalls, set a little more down elevator. Take your time in between flights – think about what happened. Trace the flight path with your hand to reinforce the complexities in your mind

*Using a spirit level to check fuselage "balance".*


*Using several coats of dope (model paint) to counter-balance wings.*

– what needs to be corrected? It can be several motions combined – try correcting one motion or problem at a time. Check the balance every time the glider is prepared for a launch.

## FLIGHT PLAN

Note that flying gliders that have pronounced flight duration requires fliers to give extra consideration to safety. Keep models to a wing span of less then 90cm. Avoid flying near roads where car drivers might be distracted or in crowded parks. If you find a field, gain permission from the farmer or owner – these are small considerations and adhering to them will enable gliders to be enjoyed by everyone.

Try to join your local model flying club, where you will find a wealth of experience and talented people, added to the fact you should be covered by a club flying insurance policy. **Under no circumstances should Freebird be used in power models of any sort**.

Be aware that bad landings and various forms of breakages are a natural part of experimenting with free flying models and these should be seen as an inevitable part of investigating flying machines, rather than a major catastrophe. Patch them up and get them back into the air.

If you think that seeing your model with a broken wing on the first flight might tempt you to jump off the hill in despair, then this pastime is not for you.

The best of luck to those of you that

might be tempted to build Freebird and venture out onto the hills this summer. □

### References

*Basic Aeronautics for Modellers*, Alasdair Sutherland, Traplet Publications ISBN 0 9510589 4 0

*Designing Model Aircraft*, Peter Miller, Traplet Publications ISBN 0 9510589 6 7

British Model Flying Association: **www.BMFA.com** – all sorts of information about clubs etc.

Radio Controlled Soaring: **www. Rcsoaring.com** – gliders, gear, events.

Traplet Publications: **www.Traplet.com** – *Quiet Flight* gliding and electric flight magazines, designing and building aircraft.