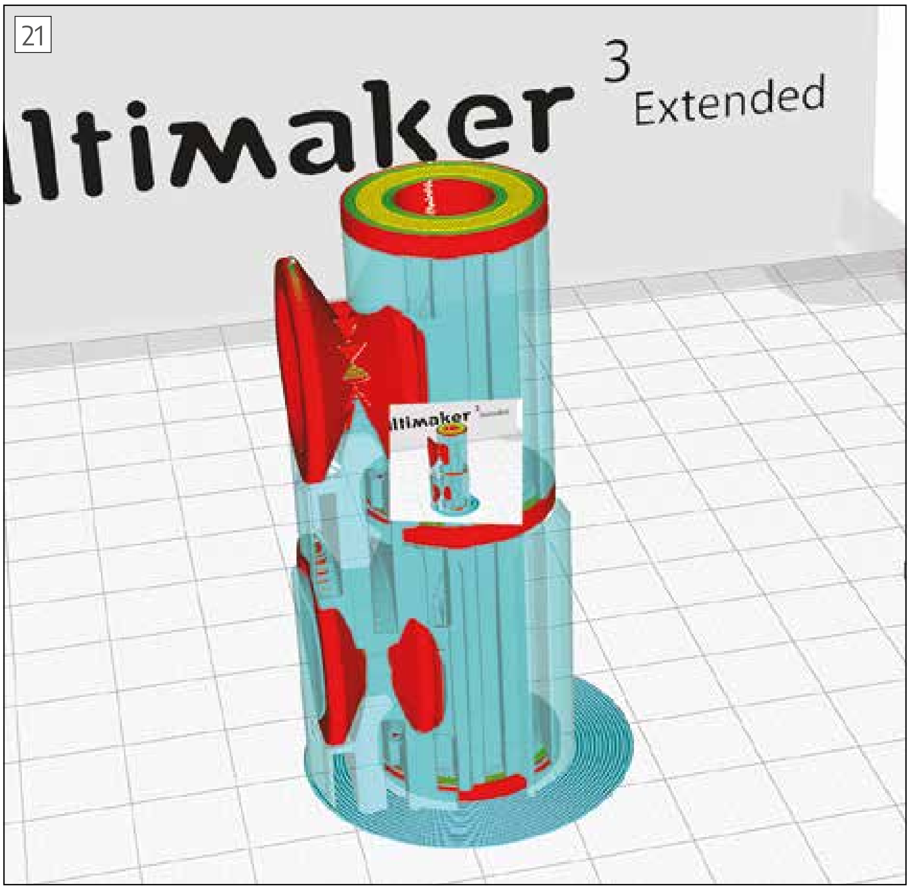
3D Printing Takes to the Air!

Mark Noel explores the boundaries of what can be achieved with 3D printing in the home workshop - Part 2

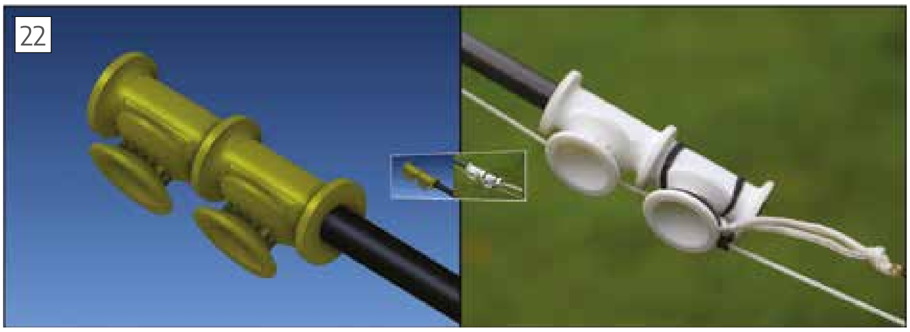
The solution for the pulleys was to print each as two halves: the 50:50 split can be accomplished in Alibre or (as I did) by applying a Z-offset in Cura to lower each pulley below the build platform by half the thickness. The two halves were joined using 30-minute epoxy. Where smaller parts are to be joined then Plastic Weld adhesive is suitable, bearing in mind that the Methyl Chloride component evaporates so quickly that there is no time for re-positioning.

Designing the toothed Capstan Wraps was a fun exercise in Alibre, combining tools for taper and parallel extrudes, extrude cuts, (for the bosses and holes), a revolve pattern (for the teeth), filleting (for the edges) and finally a mirror to duplicate a single wrap to form a pair. Deciding the print orientation (long axis vertical), layer height (0.1mm) and support density (20%) was critical to achieving a good result, **photo 21**. With a brim to ensure good adhesion to the build plate, the print time for each was 95 minutes and it was pleasing to remove the support to reveal teeth that were distinct and sharp, with all surfaces free of blemishes, **photo 22**. This exercise illustrates the need to bear in mind the 'printability' of parts being modelled in 3D. For example: limit the number of surfaces with steep overhangs; take care with the orientation of holes that need tight tolerancing; avoid tall webs thinner than 1mm. Fillets can be added to strengthen joints, while bearing in mind that radii less than 2mm will often print with poor definition.



Preparing a print of a capstan wrap in Cura. Material shown blue is the support structure with a brim to provide good attachment to the build plate.

STL files for the suspension and other gadgets described in this article can be downloaded from my website if you fancy joining this hobby (**www.aeronaut.org.uk**). The site also has a gallery of aerial images taken using this equipment. Even if you have no plans to print anything, you can explore these parts using ModuleWorks' excellent 3D viewer listed in Resources.



Alibre model and close-up of one of the printed capstan wraps. The black rubber band is added for security in case the line goes slack when flying.

Attempts at Roll Stabilisation

I have explored several methods for reducing roll of the suspension around the kite line, each incorporating 3D printed parts. The first comprised a simple passive damper comprising a pair of 10 cm polystyrene balls at the ends of a 1 metre long, 4 mm carbon fibre tube. Once in flight however, the balls oscillated up and down at about 5Hz due to cyclic eddy shedding in the lee of each ball. Incidentally, this 'flutter' was found to be the cause of wing failure in early monoplanes which replaced the earlier more strongly braced biplanes. Tip: when booking a long-distance flight always ask to go via a biplane rather than a monoplane. They are safer.

Flutter was prevented by bracing and bending the stabiliser spar with monofilament line tensioned between four short struts that raise the balls above the suspension, **photo 23**. Damping occurs by two effects: first, simple aerodynamic drag on the balls should the suspension try to roll; secondly, if the line should accelerate transversely then aerodynamic torque on the (raised) balls opposes the inertial torque on the camera assembly below.

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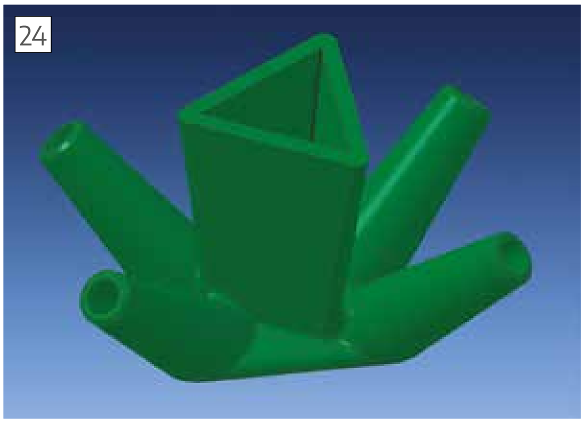
Passive ball stabiliser, braced to prevent aerodynamic flutter.



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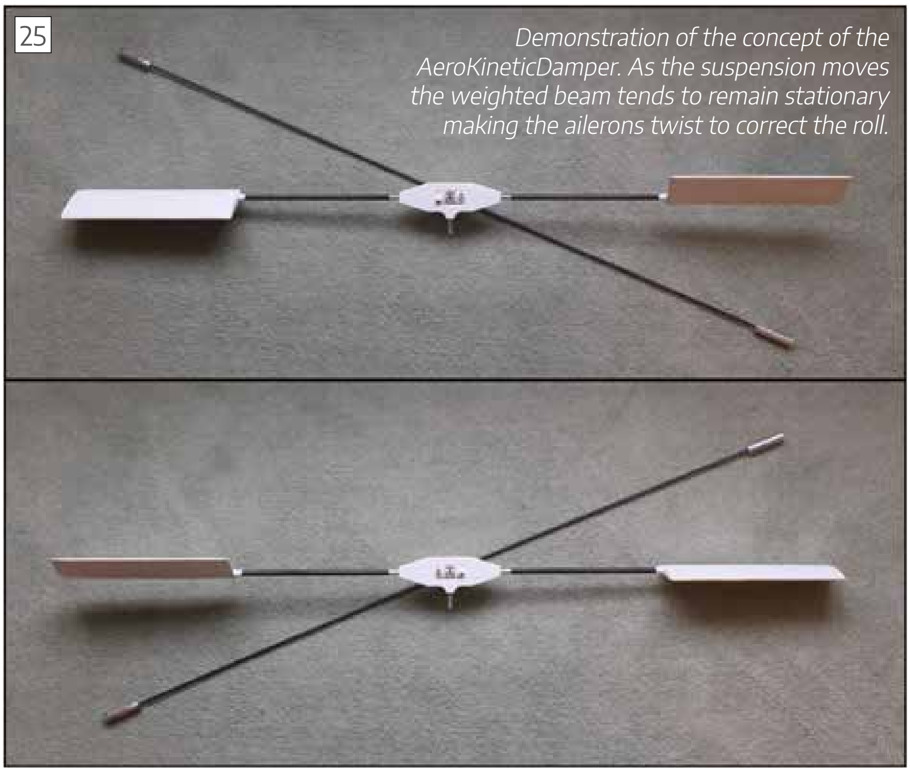
Boss at the centre of the ball stabiliser with 4 diverging pillars made by projecting from the faces of an extruded hexagon in Alibre.

I was initially flummoxed as to how to design the central 4-way boss that projects upwards at 45º. Normal practice in Alibre would be to configure a set of inclined reference planes, each of which would itself be developed off another inclined plane. A simpler alternative was to extrude a hexagonal pyramid with 45º draft which automatically generated four diverging faces from which to extrude the bosses. This pyramid was then suppressed in the design tree to leave only the bosses shown in **photo 24**. No support was needed when printing since the overhangs are too shallow and the holes came out perfectly round. In tests the flutter problem had been prevented but the damping was too small and so larger balls are on order.

The next device combines inertial and aerodynamic forces to stabilise the roll and is catchily named the AeroKineticDamper! A 1m long beam is pivoted at the centre and weighted at the ends to provide the inertial element. Whenever the suspension rolls, movement of this beam is delayed by inertia, driving a differential gearbox that moves ailerons to counter the roll as seen in photo 25. These ailerons were made of balsa and the bevel gears downloaded from GrabCAD, scaled to fit, shaft holes extruded in Alibre, and then printed at 0.1mm resolution, photo 26. Again, the assembly was mounted atop the suspension but during flight tests only modest roll damping was achieved because the ailerons are too small. However, the project did demonstrate that quality bevel gears can be made by 3D printing.

An Optical Horizon Sensor

A completely different approach to levelling the KAP platform might be to adapt the Optical Horizon Sensing Technology used in Earth orbiting satellites. Such sensors comprise a fanned-array of IR photodiodes which respond more strongly to Earth radiation than to the darkness of space, such that a sharp signal cutoff occurs at each



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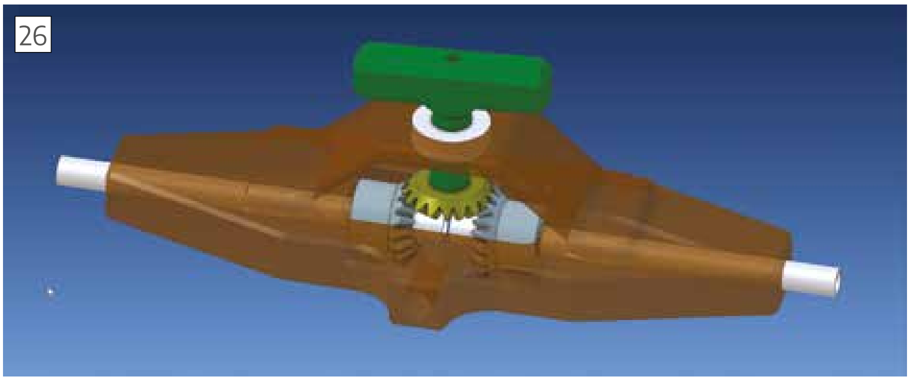
Demonstration of the concept of the AeroKineticDamper. As the suspension moves the weighted beam tends to remain stationary making the ailerons twist to correct the roll.



Alibre model of the differential gearbox at the heart of the AeroKineticDamper.

Sellex Galileo Optical Horizon sensor IRES-C.

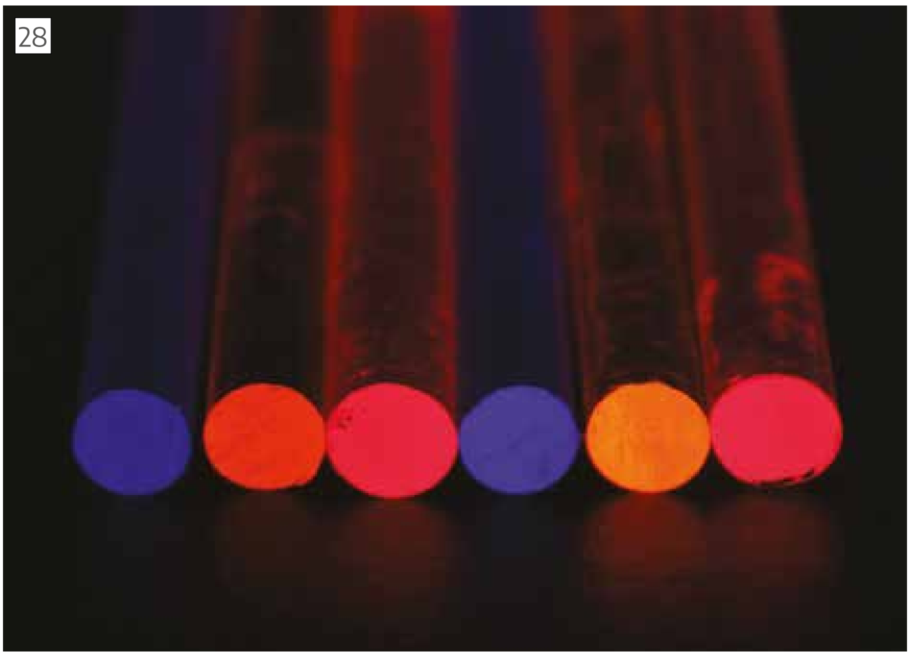
diode when its view transits the horizon. Sophisticated algorithms can process signals from these arrays and compute the horizon angle to within 0.2º. Thrusters are then fired to re-orient the satellite. An example of such a sensor is the IRES-C manufactured by Sellex Galilieo shown in **photo 27**.

In high orbit the Earth horizon appears as a smooth parametric curve which somewhat simplifies the mathematics. However, kites fly in what humourists might call Tethered Jolly Low Orbits (TJLO), with the horizon markedly roughened by the presence of trees, topography and buildings, raising doubts as to whether this technology can be adapted. But the saving grace of a TJLO platform is that the profile of this ragged horizon is largely consistent, simply reducing in vertical scale as the kite climbs.

I have experimented to see whether optical horizon sensing can orient a KAP platform. In the Womble Burrow I have a collection of Light Dependent Resistors (LDR) which have a broad spectrum response to visible, IR and UV light. I found that LDRs do not discriminate significantly between radiation from the sky and vegetation to be sufficiently effective for horizon discrimination. The solution was to design a sensor in which the LDR is placed behind a rod of fluorescent acrylic which glows brightly when exposed to skylight UV but which dims immediately when pointing at the ground which is deficient in UV. Some offcuts of this luminous plastic were seen glowing in my burrow, **photo 28**.

Photograph 29 is an Alibre model of a horizon sensor based on this principle. Light enters through a tapered conical port that shapes the view to sharpen discrimination as the sensor transits the horizon. The long axis of the ellipse defines the horizontal viewport of the sensor and matt black paint inside the cone reduces internal reflection. Incoming light strikes the fluorescent rod to create a glow that illuminates a slanting white screen seen by the LDR.

To detect roll about one axis, a pair of opposing sensors were evaluated, with the two LDRs forming halves of a Wheatstone Bridge the output of which would be null (i.e. 0V) if the illumination into each was equal. In field trials on a hill top this dual-sensor showed a clear voltage offset as the device was rolled away from horizontal. The next step was to modify a servo-testing module by replacing its potentiometer with the sensor's bridge signal and driving a



Fluorescent coloured acrylic rods, 6mm diameter.

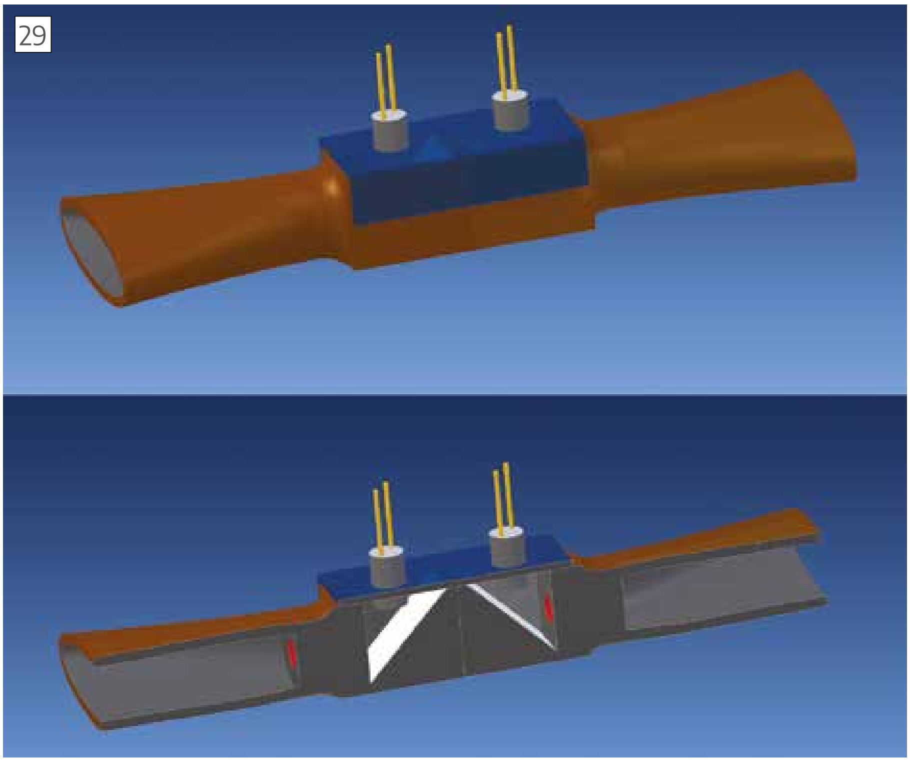
servo with the output from this module. The servo drive then re-levels the sensor array until the output is again null. This crude assembly is shown in **photo 30**. A return to the hill top proved the self-levelling behaviour of the test unit, although the accuracy was limited by the servo's resolution.

An improvement to the sensor has been to attach a shadow mask over the elliptical opening in order to soften the LDR output as the horizon sweeps past, **photo 31**. The simple BBC Basic program listed here, **box 1**, generates a mask of dots whose density and edge gradient can be configured with simple parameters. If you have a moment, then download the free evaluation version of BBC Basic and have fun playing with this dot-splattering program.

A Barometric Altimeter

The Civil Aviation Authority have granted permission to fly my KAP equipment to a maximum height of 600', subject to conditions which include maintaining altimeter records. In order to comply I have built a barometric altimeter based on two SparkFun modules; their Artemis data logger and LPS25HB absolute pressure sensor. These link with a ribbon cable, with other wires going to a 3.7V battery, Reset and ON/OFF buttons. Data are stored on a Micro SD card with readings logged at 10Hz.

Programming the Artemis is beyond the scope of this article, but what is of interest is how 3D printing was key to the project's success. The logger and sensor modules fit on two carrier boards inside a streamlined enclosure that has a TriTaper adapter beneath. The lid is secured to the casing with a pair of M3 screws that engage with corresponding threaded inserts and is removed to access the SD card. To minimise weight wall thickness of the printed parts was reduced to 0.8mm, with a layer height of 0.1mm to give a smooth finish.

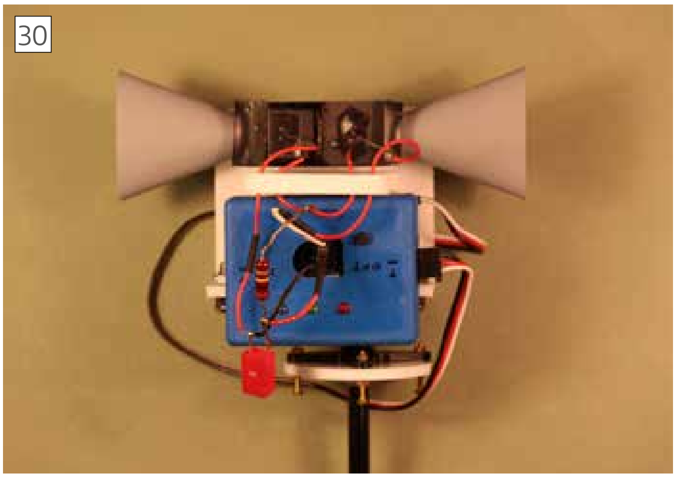


Alibre model of the Optical Horizon Sensor with a section through the assembly. Light entering the cone excites flourescence in the rod which reflects off a screen viewed by the LDR.

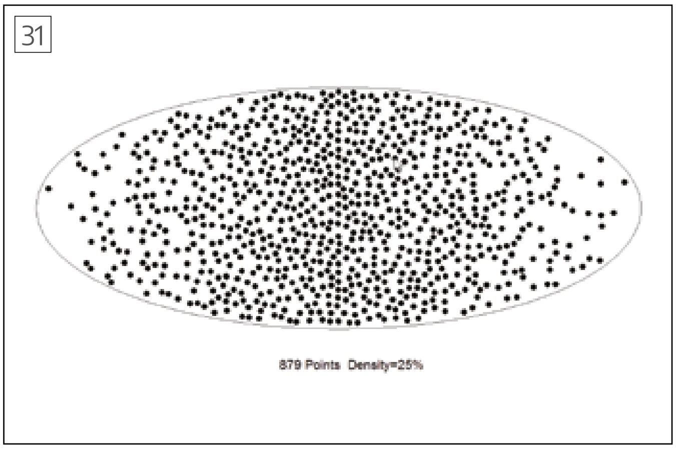
A key question when designing an altimeter, whether it be for an airliner or kite, is where best to measure the air pressure or, more specifically, the ambient air pressure not disturbed by airflow over the vehicle. Considerable effort goes into addressing this problem when finding the optimum location for an aircraft's Static Port, i.e. the place where the pressure is truly ambient and not affected by the roll, pitch, yaw or speed of the craft.

Not having a wind tunnel, I had to rely on guesswork when locating the static port. Common sense suggests that the airflow, and therefore the pressure, will be least disturbed if measured well ahead of the enclosure. In my altimeter the static port comprises an array of six 1mm holes drilled into a faired tubular probe that projects into the airflow. A collar is fitted inside the probe into which is sealed a 3mm, flexible, PVC tube. This tube feeds the air pressure to the barometric module via a 3D printed manifold bonded and sealed over the sensor, ensuring that only the static port's pressure is transmitted to the chip. **Photograph 32** shows the components of the altimeter and the assembled unit ready to fly.

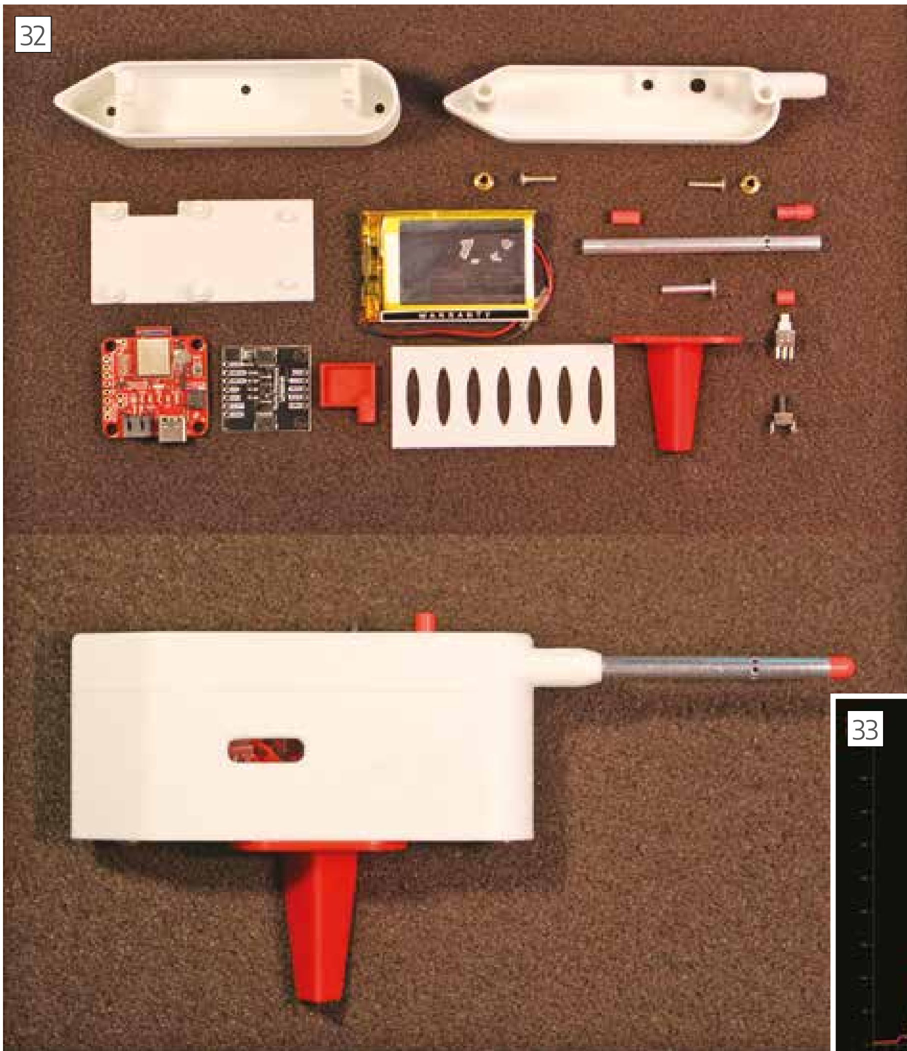
Another BASIC program calibrates,



Rig to evaluate the LDR-based Optical Horizon Sensor.



Example of a shadow mask for the optical horizon sensor made by printing a graduated pattern of dots on transparent acrylic film.



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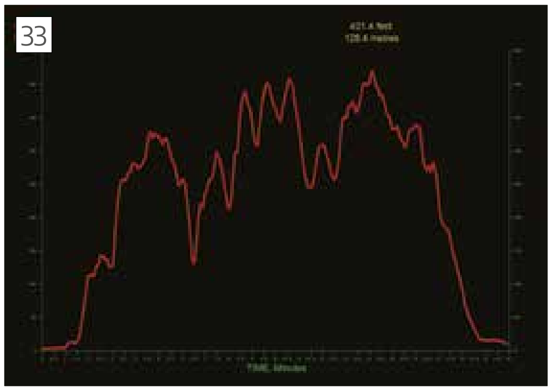
Components of the altimeter and the assembled unit ready to fly.

scales and plots flight barometric data; an example is shown in **photo 33**. The code automatically detects the peak altitude which is written in feet and metres.

The Need for Threaded Inserts

The altimeter enclosure is joined to the lid by M3 screws that engage with bonded threaded brass inserts. PLA is a difficult material to tap because of its low melting point and tendency to clog taps, even when using lubricant. As Neil described in his book, threaded inserts are the optimum solution to this problem because they distribute load from the screw into a larger volume of plastic. In MEW 225-227 I described the build of a heated tool for controlled 'heat staking' of inserts into PLA. Small quantities of inexpensive inserts in a variety of sizes can be bought on the Internet and there are simpler means for staking them as shown in **photo 34**. A temperature-controlled soldering iron can also be used. Another approach is to bond them into place using epoxy, taking care to block the insert's bore with a length of studding to prevent glue ingress.

Whichever method is used, it is essential to size the receiving hole accurately to ensure that the knurled body attains sufficient grab with the plastic. The only way to be certain is to print a set of holes with increasing bore sizes and to test the insert for a grip that does not split the plastic. In the case of M3 x 6mm OD inserts, for example, I find that a 5.9mm designed bore size results in a 5.8mm



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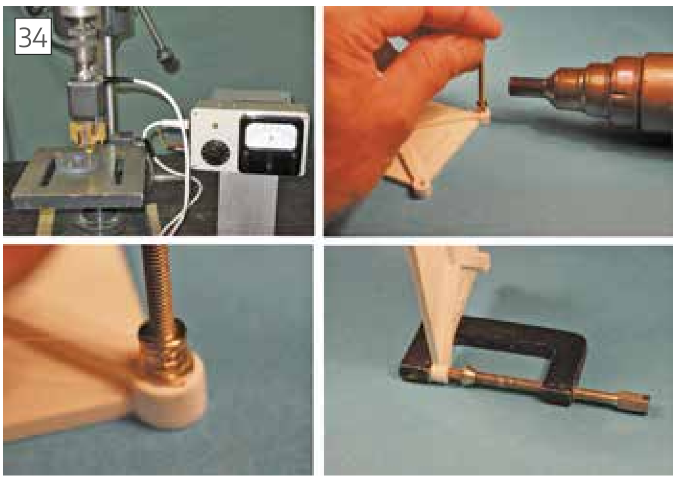
An example of the altimeter log with the peak altitude identified in feet and metres.



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Various methods for staking threaded inserts. Clockwise from top left: With heat staking machine (MEW 225-227); Hot air gun and studding; Using glue and heat; Simply forcing in with a vice or arbor press.

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Assembled PanGimbal unit.

printed hole that has strong grab.

A Panning-Gimbal Unit

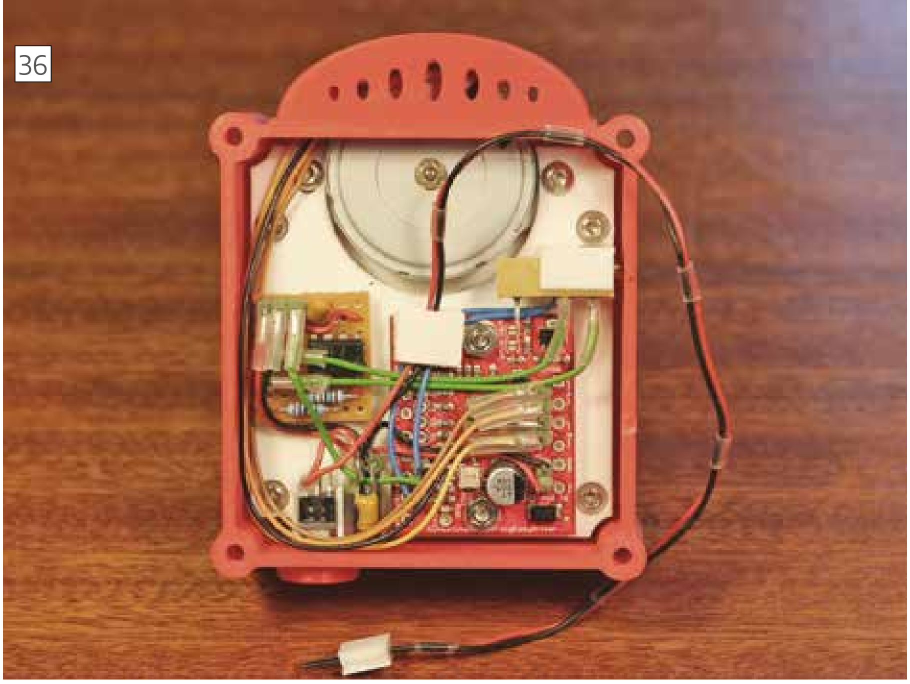
Photo 35 shows the PanGimbal unit that I use for recording aerial videos. It combines the functions of providing fine stabilisation with a Tarot 3-axis gimbal, and a motor drive that rotates the device continuously around the horizon.

The unit comprises two housings: the lower for the gimbal controller and two PP3 batteries; the upper pan unit contains a stepper motor, gearbox, pulse generator and voltage regulator as seen in **photos 36** and **37**. Redundant printers provide a wealth of components that are worth collecting for workshop projects and **photo 38** shows a small selection of the parts that I have wombled. Computer disc drives are also a source of precision electro-mechanical parts. The heart of the pan unit is a Minibea stepper motor powered by a BigEasy driver, with pulses provided by a 555 oscillator. A pair of ball bearings support the output shaft that mounts on the suspension's lower adapter. A switch and potentiometer in the circuit permit the pan rate and direction (CW/ACW) to be altered.

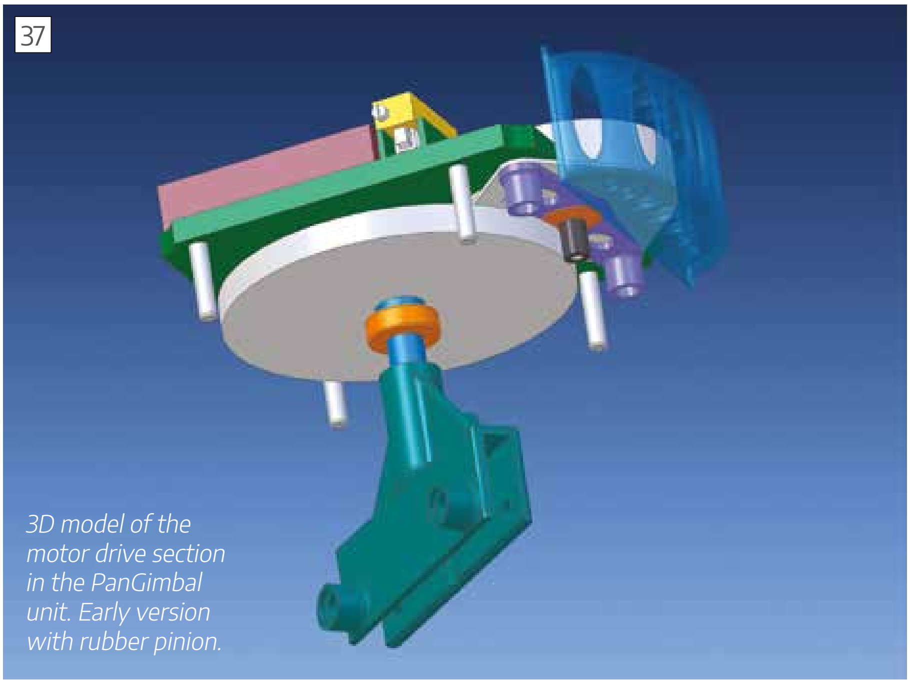
A major issue was how to gear down the motor output but with negligible backlash. Initially the gear reduction comprised a sandpaper-coated wheel on the output shaft bearing against a rubber-sheathed wheel on the motor pinion. Although this drive had zero backlash, it worked well for only a few minutes, after which the rubber had eroded and lost contact with the output wheel.

The eventual solution was to design a pair of involute gears using the free gear designer listed in the Resources. These were scaled and shaft mounts extruded in Alibre before printing with 0.1mm layer thickness and 20% fill, **photo 39**. The motor position can be adjusted until backlash is virtually eliminated. Surprisingly, even after several hours of continuous operation the backlash remains unchanged, demonstrating that 3D printing with PLA can produce rugged and low-wear gear mechanisms provided the load is kept small.

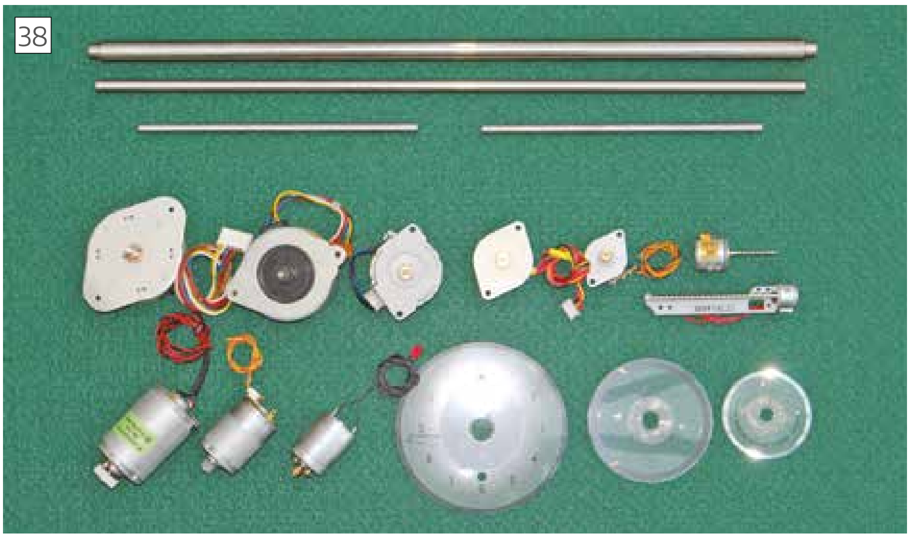
The aeronaut website shows a number of panning videos that prove the effectiveness of the PanGimbal unit.



Internal view of the PanGimbal showing the stepper motor, BigEasy Driver, pulse generator and regulator.



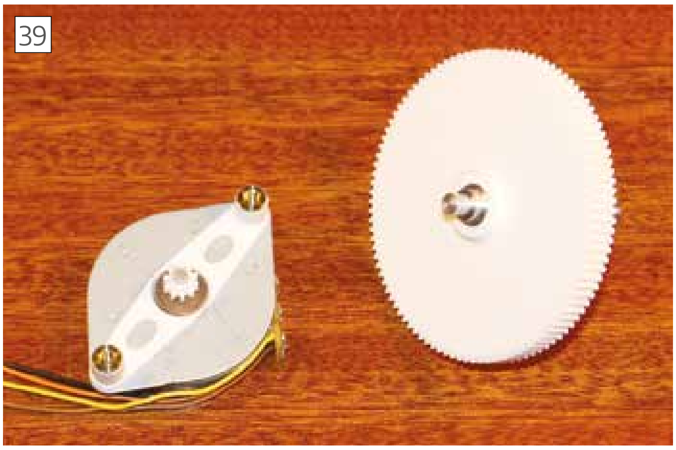
3D model of the motor drive section in the PanGimbal unit. Early version with rubber pinion.



A small selection of parts salvaged from redundant inkjet printers. These include stepper and servo motors, precision shafting and rotary encoders.

Other 3D Printed Gadgets

Photograph 40 shows a number of other gadgets made using 3D printing during this KAP adventure. These include a cam cleat and deck cleats for tethering the kite line. Next, I am making a unit that combines a GPS receiver and



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3D printed involute gears that transmit drive from the motor to the output shaft of the PanGimbal. These have provided negligible backlash and undetectable wear.

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Other gadgets produced using 3D printing that play an important part in my KAP activity. These include cleats, a camera mount and two concepts for a line payout.

environmental sensors that will mount onto the kite with the aim of extending the role of this aerial platform.

Evolution of this project has been enabled by the power of 3D printing. An old engineer friend once told me that:

There is no such thing as new ideas, only new applications of old ideas.

However, in this context it seems that modern design tools coupled with 3D printing actually do provide the potential for creating new ideas as well refining old ones. ■

Resources

Neil M Wyatt, 2018. *3D Printing for Model Engineers: A Practical Guide.* Crowood Press.
Ultimaker Bowden-feed printers: **https://ultimaker.com/3d-printers**
Zortrax Bowden-feed printers: **https://zortrax.com/**
BCN3D Direct-drive printers: **https://www.bcn3d.com/bcn3d-sigma-d25/#**
Markforged metal printers: **https://markforged.com/3d-printers/metal-x**
Formlabs SLA printers: **https://formlabs.com/3d-printers/catalog/**
Prusa MLSA printer: **https://www.prusa3d.com/original-prusa-sl1/**
Additive-X (formerly GoPrint3D), suppliers of printers and consumables: **https://www.additive-x.com/**
FastCAD 2D drawing: **https://fastcad.com/**
Alibre Design 3D engineering CAD (in UK): **https://www.mintronics.co.uk/**
Complex lattice design and analysis software: **https://ntopology.com/**
FreeCAD engineering design with FEM analysis: **https://www.freecadweb.org/**
Meshmixer lattice creation from STL files: **https://www.meshmixer.com/**
GrabCAD free STL print models: **https://grabcad.com/library**
Gibson Girl Rescue Kite: **http://thekitesociety.org.uk/PDF/Gibson%20Girl.PDF**
KAP community forum: **http://kapforum.org/discussion/discussions/**
Worldwide KAP enthusiast register: **http://www.armadale.org.uk/groupmembers.htm**
Into the Wind kite supplier: **https://intothewind.com/**
BBC Basic for Windows: **http://www.rtrussell.co.uk/**
Sparkfun Artemis logger and modules: **https://www.sparkfun.com/products/16832**
Involute gear designer: **http://hessmer.org/gears/InvoluteSpurGearBuilder**
Aeronaut projects and aerial images: **www.aeronaut.org.uk**

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Kite aerial photograph of Kerroogarroo Fort, Jurby, Isle of Man.