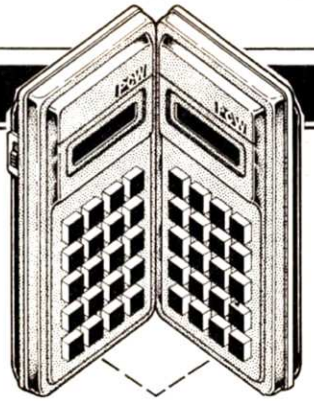


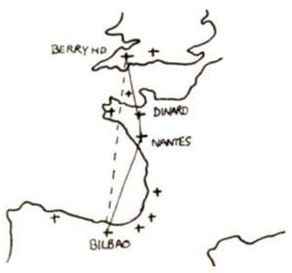
CALCULATOR CORNER

If there are still any people who consider programmable calculators to be poor substitutes for a micro they should have been awakened by the use of HP-41CV's by the Space Shuttle crews (despite the availability of no fewer than five computers). This article by M E Rankin, a BAC 1-11 pilot with Dan-Air, further drives home the point that a programmable can still be the most cost effective solution to computational problems under certain conditions.

I'M PROGRAMMABLE, FLY ME!

In early 1980 I bought a TI-59 programmable calculator with the intention of solving a quite simple problem in air navigation. The commonest form of navigation equipment in use throughout the world allows the measurement of very accurate distances and rather less accurate bearings from ground radio stations placed at suitable intervals along the airways. The display given to the pilot shows him distance to run and, by means of a deviation meter with a single needle, tells him whether he is on track, left, or right of it, in terms of angular displacement rather than distance. The maximum useful range of the groundstations is around 120 miles and they are usually less than 100 miles apart.

Airways are rarely straight, for a variety of reasons. For example, they may make considerable detours to avoid airspace allotted to the military for weapons training. The detours are often not permanent necessities and, at times of light traffic and when the armed forces are not using their bombing ranges, it is often possible to take short cuts. If such a direct routing begins at a point between navigation beacons and leads to a beacon well outside reception range, the equipment described above simply cannot cope. It is neither flying away from a radio station, nor (as far as it can tell) towards one. It cannot advise the pilot of the correct bearing to his destination. If he knows the correct bearing, the system cannot tell him whether he is on it. In short, if he wishes to take advantage of a direct routing offered to him, the pilot of such an aircraft must resort to guesstimation. This is frustrating for him because he is surrounded by navigation beacons, his ability to measure their bearings and distances is unimpaired and if he had appropriate charts and plotting facilities he could in time derive all the information he needs. A typical example of this situation is shown in the illustration. The crosses on the map are a selection of the navigation stations which are within useful range of some part of the dotted direct routing.



The solid line is a section of a common route along airways between, say, Malaga and Manchester or Cardiff, and from Bilbao leads via Nantes, Dinard and Berry Head near Dartmouth. If a route between Bilbao and Berry Head could be flown with complete accuracy in one long, straight line, 22 nautical miles would be saved — about three minutes' flying time in a BAC 1-11. An airliner of that size could cost anywhere between £25 and £75 a minute to operate, so the saving is obviously worth having. Part of this reduction in flight time would be achieved by guesstimation, unless the pilot was rather bad at it, so the amount of the saving which could be credited to any new system of navigating would be rather less than the three minutes of this example. How much less is a matter of opinion, since there is no way of measuring it. However, these figures suggest that the potential savings are not large enough to repay the cost of buying any of the very high cost equipment, such as Inertial Navigation Systems normally priced in six figures. Hence the TI 59.

Since I am no mathematician I bought the Texas Instruments Aviation Module with its ready-made programs for this form of navigation, known as Area Navigation. From the moment I opened the superb handbooks I was lost to everyday domestic life.

I found an adequate system of area navigation based on a straightforward constant-scale grid on which the locations of the navigation beacons can be plotted as pairs of X and Y coordinates. A Load module program provides for the calculation of the coordinates of the beacons, each of which is allotted a 'waypoint' number. The coordinates are stored in a pair of data registers whose addresses are a simple function of the waypoint number.

On entering a waypoint number and the bearing and distance from it, the area navigation program calculates, or 'fixes', the aircraft's position in terms of X and Y. On entering the destination waypoint number, a little Pythagoras provides the track and distance to that destination. Time of the fix and estimated speed are used to forecast the arrival time. Finally, when two or more fixes have been entered, and if the time between them is known, the actual speed achieved can be determined, and used to revise the estimated time of arrival.

The principles are simple enough, but I ran headlong into practical difficulties. To begin with, I simply couldn't key in the data accurately enough. It came too thick and fast for me to enter directly into the calculator; and when I wrote it down, the meaning seemed to evaporate within seconds. (It is an axiom among pilots that the brain drops to about one third power as the wheels retract.) That problem disappeared when I designed a form on which to enter the data. This is a type of Log and turned out subsequently to have many other uses. In a much developed form it is now an essential component of the system.

Secondly, the recommended method of constructing the model of the area required that the bearings and distances between adjacent waypoints on the chart be fed into the Load Module. That didn't work with more than six or eight waypoints because the cumulative effects of errors in these figures built up to an unacceptable level. Accuracy was regained by the laborious use of a further program for the calculation of the bearings and distances. The reasons for the initial errors then became clear — the airways charts themselves contain significant errors.

During this process the amount of keypunching required, and the destructive effects of keying errors, made it clear that a printer was required, so a PC-100B was obtained. It then became possible to trap errors more or less as they occurred: and certainly before any real damage had been done. My first successful waypoint model took two full days of continuous work, but was very accurate. It was about 1000 nautical miles long: and over that distance had errors of 0.2° and 0.2 nautical miles. Not all have been as good as that, but errors of this order are considerably less than the errors of the information fed in and are completely irrelevant for practical purposes.

The system now began to show its paces. For the first time I was able to see where my over-the-horizon destination lay and whether I was maintaining an accurate track towards it. The initial determination by the calculator of the direct tracks between well-known locations demolished a few myths among my colleagues and the significance of the well-known inconstancy and inaccuracy of the bearing information available to the pilot began to sink in for the first time. It was becoming clear quite quickly that the guesstimation methods generally in use are not nearly as good as most pilots believe, and that major deviations from the correct route must be quite common. I had also begun to be aware of some of the other shortcomings of

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the system I was using.

The area navigation programs had an irritating lack of order about them. Though the most urgently required output is the required track to destination, it was always necessary to calculate and display the distance first. A great deal of unnecessary accuracy had been built into the XY pairs specifying waypoint locations, which were calculated to ten significant figures. Other minor improvements suggested themselves, too, but of course the module programs cannot be altered. The area navigation program most commonly used was downloaded for study, and listed. Among the more interesting alterations made to it were the complete excision of 26 unnecessary steps and thanks to an idea suggested by N Harwood's article 'More Miles per Texan Stetson's (*PCW* November 1980), the XY pairs were data-packed to reduce data register requirements from 88 to 44. It slowed things down a little but the improvements made it well worthwhile.

As an aside, if any pilot is thinking of using Polar to Rectangular conversion for navigation purposes, a neat trap has been prepared for you. By mathematical convention, angles are measured anti-clockwise from the 12 o'clock position. To fool your calculator into giving you the right answer, change the sign of the bearing or angle and add 90 to it before starting. It will save you two-and-a-half days of frustration if precedent can be taken as a guide.

The system worked very well once I was used to it. While I could never prove quantitatively the value of the system, it was subjectively an obvious improvement. This was emphasised for me when an unexpected headwind left me too short of fuel to continue legally to my destination. An en-route refuelling stop was necessitated by the fuel shortage, but a last minute direct routing brought the destination just within lawful reach again. I would not have felt it prudent to guesstimate that last leg for stakes like that, but the confidence given me by the area navigation system made the decision to continue easy and well-justified. That day the TI-59 paid for itself and the printer several times over.

So, I was convinced, and I had found that there were several other obvious uses for it. By the end of the year I had written programs for the calculation of aircraft trim, for pre-flight fuel calculation and for a different kind of area navigation. But I had also found some fairly severe limitations of the system.

The TI-59 display is quite invisible in strong light — such as one commonly finds at 33,000ft. Its rechargeable battery is good for about three hours and my flights sometimes lasted four hours — one way. Card reading and writing was uncertain and often required several current-consuming attempts. Battery retaining clips broke off twice because they are not robust enough to take repeated use of the print cradle. Two or three identical digits would sometimes appear no matter how staccato I tried to make my data entry, due to the lack of keyboard debouncing.

The Aviation Module, too, has some limitations, partly in the programs themselves and partly in the concepts used in designing the whole package. Having once recovered from one's initial admiration at the range and number of the programs presented, it was possible to wonder why some of them had been written at all. There is a strong bias toward American-owned light twin-piston-engined aircraft, but it is apparently neither aimed exclusively at them, nor wholly satisfactory for any other category. The Aztec owner will be supremely uninterested in his new-found ability to calculate Mach number and any jet pilot will be frustrated by the trim calculations which allow him to calculate the effect of varying fuel load only if he uses petrol.

Sorriest of all, however, is the unnecessary clash of flags and data register allocations. With any type of navigation and any type of aircraft, the calculation of True Airspeed will sooner or later be required. If the Aviation Module is used for this purpose while area navigating, one flag and three data registers are overwritten, possibly ruining the area model. The rhumbline track and distance program

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(which is used to find the way between two positions spelled out in latitude and longitude) is even worse because it quite gratuitously wipes out all of the data registers and thus the all-important route model. These related functions ought to be capable of operating without mutual interference.

It was with these thoughts that I recommended to my company that the programmable calculator looked promising for the area navigation task. I had read Dick Pountain's description of the HP-41C (*PCW* April 1980) and discovered its larger brother the HP-41CV in the shops. This calculator had so many characteristics which improved on my TI-59 that I asked the airline to let me carry out a trial on it. The idea was to quickly translate a few of my existing programs into HPese, test them and try them out with some of my colleagues. After some very hard talking and an unusually successful demonstration flight I was given the money to buy two HP-41CVs, two card readers and a printer, with appropriate supporting stationery. With an astonished gasp or two, a colleague and I began work in June 1981, formally equipped and formally tasked (on an unpaid basis) to write a report by the end of October.