NEWSLETTER ARCHIVES

APPROACH AND LANDING
by Brian Kendal

Unfashionable as it may seem to say it in this day and age, there is always a measure of danger in any flight by an aircraft. With modern aircraft, this is now so low that you are in far greater danger during your journey to and from the airport, but it was not always so.

Let us first consider where this danger lies. Having boarded the aircraft, the first part of the journey is at relatively slow speed along the taxiways to the runway. During this time the aircrew will carry out a series of checks to ensure that the aircraft is in all ways ready for the flight.

On arrival at the runway, and after receiving permission from the Control Tower, power will be applied, the aircraft will accelerate rapidly down the runway and at some point flying speed will be reached, the control column will be eased back and the aircraft will leave the ground. There then follows a short period of intense activity by the flight crew while they retract the flaps and undercarriage and trim the aircraft for ascent to cruising altitude.

That is the first point of danger, for if an engine fails, the load and trim of the aircraft has been seriously miscalculated or there is slush on the runway, flying speed may not be attained and if the take off is not aborted in time, an accident is certain. However, in modern aircraft operating practice, slush and snow will be removed from the runway before an aircraft attempts to take off, load and trim is checked and rechecked until there is little possibility of error and aircraft design is now such that if engine failure occurs in the later stages of take off, the remaining engine has sufficient power to ensure take off and to maintain the aircraft in the air until such time that the aircraft can again land.

After a successful take off, there is little danger in the cruise mode of the flight except from collision, for natural enemies, such as icing or inclement weather, can either be countered or avoided. Collision is avoided in commercial flying by very comprehensive air traffic control using both primary and secondary radar surveillance. This is so effective that, for example, there has been no air-to-air collision in British controlled civil airspace since the system was set up in 1947 and other European states have similar records.

The most dangerous part of the flight by far is that of descent and landing. In clear daytime conditions this presents little difficulty to the experienced pilot whilst in similar weather at night, modern airport lighting systems ensure a similar level of safety.

When the weather deteriorates, however, difficulties increase alarmingly and it is in these conditions that most aircraft accidents occur. Most modern airports are now equipped with instrument landing systems of various grades which can enable the aircraft to automatically approach and land in weather in which even the birds are walking - but it was not always so and it has been a very long journey to reach this happy state.

Let us first try and get some idea of the difficulties which we must face. Although airfield runways are between 50 and 150 yards wide, this does not give much room to spare, for even the small 737s and BAC 1-11s have a wingspan of a hundred feet and the big widebodies are at least twice that. There are plenty of runways in the world where the wingtips of a 747 will overhang both sides of the runway. The approach speed will be somewhere in the region of 180 mph, slowing to perhaps 140 on crossing the airfield boundary.

To give some idea of the problem in really bad conditions, imagine that in a visibility of 20 yards or less, you have to drive a car across a field at a speed of not less that 60 mph and without slowing down, exit through a farm gate on the far side whose exact location you have not been told. Extrapolate this problem into three dimensions and you have the dilemma of a pilot without navigational aids.

Of course it is not always that bad, although there are more landings in CAT 1 or worse conditions (1/2 mile visibility, 200 ft decision) at Heathrow than any other international airport. Instrument conditions exist about 5% of the time there.

The first problem for the pilot is to descend through the cloud from cruising height. Whilst in cloud, the possibility of collision is greatly increased, but you must rely on Air Traffic Control that there will be no conflicts. As you approach the airfield, you must align yourself with the runway which you cannot see, for when you break cloud you will have little time to make corrections. If you are not quite sure where you are, in mountainous areas you may find that the cloud suddenly changes to granite - but in that case you will not have to worry for very long.

You will be moving forward at 150 mph and descending at more than 600 feet per minute. When you first see the runway, you will have less than 15 seconds before your wheels touch down. You have that time to align the aircraft to the runway, correct your descent rate, put the aircraft into landing attitude and, in the last few seconds, check the descent rate so that you make a smooth landing. With a non- instrument approach, you may not have time to make these corrections, and then the decision not to land must be made within about two seconds of first sighting the runway, for it takes time to halt the descent, wind up the engines and start climbing for an overshoot.

The earliest attempt to overcome these problems was in 1916 by the RNAS who developed the "Ground Proximeter". In those days aircraft landing speeds were low, descent speed similar and airfields were large grass areas which did not require landing at a specific place. Altimeters were fitted to the aircraft, but the difficulty in low visibility was to decide when to "flare" for the landing. The RNAS came up with a very simple device which comprised a length of cord terminating with a weight, hanging 15/20 feet below the aircraft. When the weight touched the ground, the tension was relieved and a light flashed in the cockpit telling the pilot to flare for landing.

Another suggestion about that time was from Prof. Lindeman (later Lord Cherwell and Churchill's scientific adviser during WW2) whose idea was that a series of balloons should delineate the approach path, flown at such a height that they were above the cloud tops and at varying heights such that if the pilot flew adjacent to them, he would be on the correct descent path for the airport.

In the early 1920s a sound mirror was used at Biggin Hill. A klaxon horn was placed at the focus and the mirror was pointed along the desired approach path. The pilot listened for the sound, and if he heard it above the wind noise he knew that he was on course. Unfortunately the power required was immense and whenever used it scared all the cattle for miles around and shattered windows at the other side of the aerodrome. It did not see much use.

At this point people began to consider methods of using radio waves to assist in navigation.

The first aids were to assist aircraft whilst en-route. Ground based direction finding had been in use for a number of years and during WW1 both sides in the conflict had developed extremely accurate chains of D/F stations to monitor their opponents transmissions. These same stations could also be used to provide navigational guidance to their own aircraft. Zeppelins used such advice when bombing the United Kingdom and some commanders claimed that the quality of the fixes obtained was as good as or even better than those obtained from astronomical sights. One of the main problems, however, was that considerable bearing errors could be generated by both coastal refraction and atmospheric conditions. Notwithstanding this, during the 1920s a chain of D/F stations was set up with Croydon as the master with Pulham in Norfolk and Lympne in Kent in order to assist aircraft on continental routes, particularly to Paris.

The standard of service must have been higher than might be expected, for in the very early days of my career I met a man who had served as a wireless operator on the Imperial Airways Silverwing Service to Paris and he told me that using D/F and CW communication they made let-downs into Croydon often with a visibility of only a few hundred yards. The instructions were received by the Radio Officer who passed the information to the pilot in the form of notes on paper slips! However, this cannot be compared with present day for the aircraft had only to land on the field and the touch down speed was under 50 mph with the big HP42 biplanes. It was a remarkable feat nevertheless.

Few realised it at the time but the principle of the next stage had been developed before the first radio had been installed in an aircraft. This was the Scheller "Course Setter".

Even Heinrich Herz, in his earliest experiments in the 1880s had realised that loop aerials exhibited some directional properties but at that time there was not much call for aeronautical navigational aids. The work was taken up by Major Round in 1905, but he discontinued his investigation due to the low sensitivity of the receivers of the time.

Several other workers were investigating the directional characteristics of aerials but it was Otto Scheller who realised that a sharp beam could be generated by intersecting the edges of two relatively broad beams. This was the Scheller "Course Setter" of 1907.

In the early 1920s this was picked up by P.D.Lowell from the American Bureau of Standards and in 1924 the Bureau published details of a station using crossed loop antennas and a quenched spark transmitter. By energising one loop for a short period and the other for rather longer, the aircraft would hear either dots if on one side of the desired course, dashes on the other and a continuous transmission when on the correct course. In time, other combinations were of interlocking signals were used such as As and Ns and Us and Ds.

Further development enabled the course to be moved without moving the aerials and also distorting the pattern so that the four courses were not at right angles but could, within reason, be directed in any desired direction. This became known as the four course radio range and remained in use for many years. I well remember that one was still in use at Burtonwood in Lancashire until well into the 1950s.

Enroute navigation was also assisted by a rotating loop fitted to the aircraft working with ground beacons and commercial radio stations.

Initially the loops were rotated by hand but by the mid 1930s, automatic systems were available which were given the name "Radio Compass". Radio Compasses are still carried on modern aircraft for the ground equipment is inexpensive and most airports have at least one in their vicinity. In the third world, they are often the only aid available, for their maintenance of modern, more complex aids often leaves much to be desired. For example, when I visited Guyana some years ago, the VOR (VHF Omni Range) beacon was operating with a 15 degree error - and there was nobody who knew how to correct it. I was familiar with the equipment and offered to put it back on course - but my offer was refused because the said everyone knew of the error and if it was corrected it would cause confusion!

Whilst on the subject of beacons I would like to mention the beacon at Livingstone in Zambia. This was originally installed to facilitate the South African Service by the big Imperial Airways flying boats in 1936 which landed on the Zambesi just above the Victoria Falls. The 400 ft mast installed then was still being used in the mid 1980s and may well remain in use today. Surely this must be the oldest navigational aid in use in the world.

At this point, radio techniques had advanced sufficiently for aircraft to find their way reasonably accurately from one airfield to another without other ground based references. However, the problem still remained that should, on arrival at its destination, the aircraft find itself above cloud, how could it descend through the murk at the right place and, furthermore, be sure that it would not make a far harder landfall than would be desirable.

To counter this problem two procedures were adopted, both of which have survived with slight modifications, to the present day. Airfields fitted with D/F guided the aircraft to the airfield. During the initial phase of the approach the aircraft was informed of the cloudbase and the airfield barometric pressure(QFE). During that time also the aircraft descended to a predetermined height, usually about 3000 ft. When the aircraft engines were heard at the airfield, instructions were given for it to turn onto a course which was the reciprocal of the landing direction. The aircraft immediately started descending at 500 feet per minute and maintained this for three minutes. At this time the descent was halted and the aircraft was turned 180 degrees in level flight. Aligned now for landing, the descent was recommenced and after two minutes, the aircraft should be at 500 feet and one minute's flying from the airfield. If still in cloud, then there was plenty of time to initiate an overshoot procedure and try again or divert to another airfield. This technique was used for many years after the war when VHF D/F gave more accurate bearings and a very similar procedure could be followed using the radio compass with a beacon or a VOR on the airfield, but in these cases the "Cone of Silence" would be the point at which the outward run would be commenced. Even today, this is the standard instrument approach procedure for many small airfields.

Using these procedures, it was now possible to fly considerable distances without ground reference and, provided that the cloud base was above four or five hundred feet, successfully land at the destination airfield.

By the late 1920s, however, air transport was becoming more commercial - and diversions or cancellations due to weather were expensive and therefore unacceptable. The search was therefore on for guidance for that last 500 ft of the descent.

In 1930 the American Bureau of Standards proposed a system whereby the landing direction was defined by a transmission on 330 kHz from a radio range type aerial system with the difference that instead of interlocking Morse signals, two tones were transmitted of 65 and 85.7 Hz. In the aircraft receiver, these were received, applied to filters, detected and used to energise a centre zero meter. This was easier to interpret than the interlocking audio signals and therefore could be flown more accurately. The edge of the airfield was defined by the cone of silence over a simple beacon modulated at 40 Hz, again on 330 kHz. This considerably improved the quality of the azimuth guidance but did not address the problem of vertical guidance.

It was left to F Dunmore to meet this need when he suggested that if, in addition to the Bureau of Standards system, a VHF signal on 93 MHz was transmitted from a location at the upwind end of the runway, if the aerial was mounted at a suitable height, then a line of equal field strength would approximate to the require vertical guidance pattern. Later, the modulation frequency of the airfield boundary beacon was changed to 1000 Hz so this could be monitored aurally whilst the navigational guidance below 200 Hz could be filtered from the headphones.

A final development of this system was the addition of a further marker beacon at a point from which the vertical guidance should be followed.

Using this system pilot M.S.Boggs made the first recorded "blind" instrument landing on Sept 5th 1931 onto a runway 2000 ft by 100 feet although there was a safety pilot in the front cockpit in case of emergencies.

All the work which I have so far described took place in the United States, however, Europe was not inactive for, as any American pilot will tell you when coming over here, European weather is a completely different ball park. The leaders in this were the Lorenz (now SEL).

The difference between the approach of the Americans and the Europeans was that Lorenz plumped immediately for a high frequency system operating on 33 MHz and used the original Scheller interlocking tone system. The increase in frequency necessitated a complete rethink of the aerial. This could now be simplified to a single vertical dipole with reflectors on either side which could be alternately disabled by open circuiting at the centre.

This shifted the radiation pattern from side to side to provide guidance. As the basic horizontal guidance was on VHF, this could also be used for vertical guidance, using a contour of equal signal strength.

Progress along the approach path was indicated by two marker beacons operating on 38 MHz, one approximately 3 km from the airfield which was modulated by dashes of 700 Hz and an inner marker at the airfield boundary radiating dots modulated at 1700 Hz. The system was also taken up by Standard Telephones and Cables who produced a similar system for the United Kingdom and the RAF. Although no vertical guidance was provided, this system, known as SBA, remained in wide use until about 1970, the last one in the United Kingdom being at Stansted Airport

Notwithstanding these developments in the 1930s, Other systems came into use, but I would like to describe one other which required completely different parameters from those previously described. I refer of course to those used by the large German airships which were such a feature of early aviation.

The real experts in this field were, of course, the Zeppelin company whose pride and joy was the Graf Zeppelin (the LZ127) which performed over 150 scheduled flights across the South Atlantic as well as many others including a round the world cruise.

The problems with a large airship are rather different to heavier-than-air craft for they have immense duration and, if conditions are bad, are quite capable of heaving to like a ship and waiting for conditions to improve. They are also extremely long (around 1000 ft) and thus by placing D/F loops fore and aft, can triangulate their position on a single beacon with reasonable accuracy.

The system devised by Telefunken was to mount three MF beacons in trucks, two of which were in line with the wind with the landing ground between. The third was located at right angles to the line at a point opposite where the airship has to stop.

The equipment on the airship includes three D/F sets, two of which operated pointers on a common scale. The ship slowly approached from the downwind, using the first two beacons and ensuring that their bearings were coincident. when the bearing of the third beacon indicated at right angles to the ship, the mooring lines were dropped and the ground crew pulled the ship down to earth.

The main problem with all the systems described so far for heavier than air craft was that the vertical guidance provided a continuously varying angle of descent. This was, perhaps, acceptable for small light aircraft which were quite manoeuvrable, but transport aircraft were getting larger all the time and consequently less able to follow continuously varying angle of descent. The search was then for a system which provided a straight line approach. This was brought to a head by a report in 1938 which made certain recommendations which culminated in a specification which eventually became known as the SCS 51.

I will not go into details of the specification but among the requirements was that the guidance should be in the VHF band, all courses should be straight line and that the markers should be on 75 MHz. Comprehensive monitoring should be included.

Instrument Landing System as we know it today is a direct descendant of this specification.

The first consideration was for the azimuth guidance. The signal carried modulations of 90 and 150 Hz which were generated in two parts known as CSB (carrier and sidebands) which is common or garden amplitude modulation, and SBO (side bands only) which is Double Sideband Suppressed Carrier. These signals were fed in varying phase and amplitude relationships to a row of Alford loop aerials and the resulting space pattern was such that 90 Hz modulation predominated on the left hand side of the approach path and 150 Hz on the right. On the centre line the depth of modulation of both tones was the same. In the aircraft, the signal was fed to 90 and 150 Hz filters and their outputs applied to the vertical pointer of a cross pointer meter. The phase of the meter was arranged such that if the aircraft was to the left of centreline, then the meter moved to the right. In other words, follow the needle.

The next part was in some ways more difficult in concept, but in engineering terms more simple, for to provide vertical guidance, use was made of the vertical polar diagrams of horizontal dipoles at various heights. The required pattern was that 90 Hz should predominate above the approach path and 150 Hz below.

A 90 Hz modulated signal was first applied to a dipole about one and a half wavelengths above the ground. This provided a single lobe at an angle of about 10 - 15 degrees from the horizontal. The 150 hz modulated signal was then applied to a dipole several wavelengths above the first. We all know that when you raise an dipole to several wavelengths above ground, the vertical radiation pattern splits into a number of lobes. By careful selection of height, the lowest lobe could be placed below that of the 90 Hz aerial and therefore there would be an angle where the signal from both aerials were equal. By careful selection of aerial heights, this line could be arranged to delineate the required glide path angle, which is about 3 degrees above the horizontal. To reduce the height of the aerial array, this system operated at about 330 MHz.

In the aircraft, a similar system to the azimuth receiver was used with the exception that this receiver energised the horizontal needle in the meter. It is an interesting technical point that the earliest glide slope receivers used a super-regenerative detector.

The SCS51 system was completed by three marker beacons operating on 75 MHz.

The SCS 51 system came into use during WW2 and subsequently spread throughout the world under the name Instrument Landing System .

Although the basic principles are the same, improvements in stability and, more particularly Glide path antenna design have greatly improved the quality of guidance. For example, the GP system I described is know as an equi signal glide path which is not renowned for its accuracy. Since then many other systems have been developed which are both more stable and more reliable. I described this system only because it was the original and the simplest to describe! Similar stability improvements have been made to the localiser and, furthermore, the beam has been tightened up considerably to minimise course deflections due to reflections from terrestrial objects.

With modern ILS systems, the quality of guidance is such that with suitably equipped aircraft a landing can be made in CAT3B conditions which is basically 50 yards visibility - which isn't very much for an aircraft travelling at 140 mph, with a decision height of 12 feet which is purely academic! . The next stage will be for guidance to be provided from the runway to the stand.

With this standard of accuracy available, consideration had to be made to take the most unreliable element out of the loop - the pilot. For this to even stand a chance of acceptance the system had to demonstrate a reliability far higher than that of a human pilot and for that reason it was decided that an acceptable reliability would be for a statistical chance of an incident or failure in not less than 1 in 100 million landings.

On the ground this meant comprehensive monitoring of the signal and changeover to hot standby equipment within 20 milliseconds of a failure. In the air, if two receivers registered different outputs it would be impossible to decide which was correct. Triplicated systems are therefore installed with guidance being taken from a majority decision. The flight control systems are similarly triplicated, with often dissimilar hardware and software systems being used to minimise the probability of software error.

This is basically the state which we are in at the present day on the vast majority of airports in the world.

Throughout this article I have covered many systems, but I have missed many more. Many of you will be surprised that I have missed out the ground controlled approach talk down which is still in use (under the name Precision Approach Radar) in many military airfields. This was used in civilian aviation until the mid 1960s, but with the development of ILS it became redundant. Similarly, I have not described the wartime Blind Approach Beacon System or BABS which also used radar techniques or even MADGE which has not seen use in civil airfields although it is doing a magnificent job for the military.

But finally, where are we next going to? In 1969 the International Civil Aviation Organisation decided that it was time to look for a replacement for ILS and that the new system should operate in the 5000MHz band. Ten years later a competition was held, and after much controversy, the American Time Referenced Scanning Beam system was chosen.

The principle of operation is essentially quite simple. The ground equipment emits a narrow beamwidth signal which sweeps to and fro across the approach path at a very precise speed. The equipment in the approaching aircraft measures the time interval between the to and fro sweeps and from that deduces its angular position. To/fro sweeps are made alternately in both azimuth and the vertical plane. In addition to the directional transmissions, a Precision Distance Measuring Equipment is installed on the site which gives "distance to run" and this completes all the information for the aircraft to fix its position. On receiving the signals, the aircraft equipment determines its position which is then compared with preset parameters so that the aircraft can be automatically directed on any desired approach course. The signal format makes time available for an exchange of data information between aircraft and ground.

A number of firms have manufactured equipment to this specification and there is no doubt that it works extremely well. I have experienced more than a dozen demonstration approaches on MLS at airports on both sides of the Atlantic which were extremely impressive, but despite this, there are few installations in Europe and these are experimental.

The only airport which I know which has only MLS is Whistler in the Canadian Rockies. I have flown on the Whistler approach, this being in really thick conditions. When the weather cleared and I saw the approach path, I was wondering whether I could chicken out and walk back!

The problem is that there is really a chicken and egg situation. Airlines will not fit the equipment until most airports are equipped, whilst airports will not install MLS until there are sufficient aircraft equipped to make the investment worthwhile. The upshot is that the date for withdrawal of ILS has been put further and further back, with the result that at many airports the ILS equipments are nearing the end of their useful life - but they are reluctant to bear the expence of replacement with such an uncertain future.

The whole situation now has been further complicated by one further development - the constellation of satellites for the GPS is now complete and, as far as the United States is concerned, fully operational.

It is my opinion that the 20+ year gestation period for MLS was just far too long. In comparison SCS51 took 2 years. In the meantime GPS has come to the state where it can provide adequate guidance for the vast majority of airports in the world. It is United States policy that GPS will replace all other navigational aids early in the next century, although the Europeans do not agree with this.

GPS is virtually a hyperbolic navigation system in which the transmitting stations are located on satellites. In the transmitted data streams, full details of the orbits are provided and at least three are visible at any one time anywhere in the world.

It is not my intention to describe the GPS system tonight for to give it justice would require the whole evening and more, but I will say that two levels of navigational guidance are provided, the most precise being available for the military and government surveyers. The other transmission only guarantees a fix accuracy of 100 metres but in practice can be considerably better than this. The whole problem lies in the fact that this accuracy can be varied by the U.S.military using a process known as Selective Availability. This, however, is scheduled to be switched off early in the next century.

We therefore have a very precise aid which will certainly reach CAT 1 standards for approach, but can, at present, be degraded by a factor of 10 without warning at the whim of a military organisation. However, various means of overcoming this are available, one of which is Differential GPS where corrections are transmitted from nearby ground stations and metric accuracy is possible.

That therefore is the position today - so whether the world goes for MLS approaches or GPS predominates is really a matter of economics and politics rather than technical factors. That is just the facts of life in the world today.

Brian Kendal G3GDU

Brian Kendal, G3GDU can be contacted by email

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