THE JOURNAL OF NAVIGATION (2008), **61**, 71–85. © The Royal Institute of Navigation
doi:10.1017/S0373463307004511 Printed in the United Kingdom

Airborne Doppler Radar Development by the Decca Company

Trevor Gray and Walter Blanchard
(Email: wblanch@ntlworld.com)

This paper is intended as an historical document describing the entry and success of the Decca Radar Company into the production of Doppler-based navigation units. It is based on an original personal paper written in about 1970 by Trevor Gray, then Head of Doppler Department, Decca Radar, updated and edited with additions by Walter Blanchard (past President of the RIN) assisted by Trevor Gray in May 2007. The paper first covers the basic theory and principles of Doppler radar systems, continues through the setting up of the Decca Doppler Department in the mid-1950s and the production of the first transistor-based Doppler system. Success led to the development of both civil and military Doppler systems culminating in the Decca Doppler 70 Series which was fitted to some 30 types of aircraft and helicopters, worldwide.

KEY WORDS

1. Decca Doppler. 2. Airborne Radar.

1. INTRODUCTION. In the late 1940s it was realised that it should be possible to design a self-contained system to obtain aircraft speed directly by the measurement of the Doppler shift on reflected radio signals from the ground. For example, if an aircraft flying towards a ground receiver at 500 kts makes a transmission in the standard aircraft am communications band (118–137 MHz) at 128 MHz, it would suffer a frequency shift of 95 Hz upwards. If this signal were then reflected from the ground back to the aircraft it would undergo a second Doppler shift and be received back at 190 Hz higher than its nominal frequency. The mathematics are quite simple, the frequency offset is calculated by dividing the aircraft's speed in the direction of the receiver by the wavelength of the transmission, in this case 222 m/s divided by 2·34 metres, 94·87 Hz. Put crudely, the aircraft is adding wavelengths because of its speed and thus making the frequency higher. The reflection back occurs at this higher frequency and undergoes a further identical shift at the aircraft making it twice as much. All that is needed is a way of measuring this frequency shift and turning the result into distance flown in one second. This is often obtained by simply mixing the return signal with an attenuated version of the outgoing signal directly at the radio frequency involved, eliminating any problems with frequency drift or not knowing exactly the outgoing frequency. Simple enough to be used in speed cameras, as many of us know to our cost! An aircraft, being at some height, measures slant speed which must be translated to speed over the ground by applying a correction for height and

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

distance. There are also further complications due to aircraft roll and pitch, climb and dive, and the type of surface reflecting the signal. Partial or complete compensation may be made by using several narrow beam transmissions pointing fore and aft and sideways, known as "Janus" systems after the Greek god who could see both ways simultaneously. To obtain these narrow beams from reasonably small antennas microwave frequencies must be used, generally in the 8·5–15 GHz region and the Doppler shift becomes correspondingly much larger (7·4 kHz at 10 GHz). A side-benefit of multiple beams is that vertical velocity can also be obtained.

If the aircraft has significant drift then the maximum Doppler shift will not be obtained along the aircraft's axis but at some angle to it and a measurement of this angle provides a measurement of drift. One way used in the early systems was to physically rotate the Doppler antenna to obtain the highest value of Doppler frequency but the method has obvious disadvantages in that a much bigger aperture or radome than that required for a fixed antenna is required in order to accommodate rotation, and mechanical limitations mean it cannot cope with drift angles much over 30°. Later systems used fixed antennas and computed drift through manipulation of the multiple beams with appropriate processing. Positive, negative and vertical velocities could be derived to accommodate helicopter requirements.

The main errors of Doppler systems, apart from those caused by aircraft manoeuvres, were due to the reflecting surface. Reflections from a smooth sea have a different spectrum from those from rough land which create offsets that must be compensated. In high-accuracy equipment this was done by the operator setting a "land/sea" switch, with consequent opportunities for mis-setting, although later some manufacturers introduced mechanization of this function at the cost of considerable complexity. Decca never embraced this philosophy as a typical error of say 1·5% was usually acceptable for a dead-reckoning aid periodically updated by other methods.

Doppler basically provided the navigator with aircraft drift relative to fore-and-aft airframe direction and speed-over-ground, the essentials of a dead-reckoning system, but drift still had to be translated into actual track-over-ground. That involved another measurement, the actual heading of the aircraft, usually measured by means of a gyromagnetic compass in the 1940s and 50s. It was not until the 1970s that inertial systems came into general use and relegated magnetically-controlled compasses to standby use. The importance of proper magnetic compass calibration was such that complicated swinging systems involving much time and effort were used, but heading remained the weak point and could introduce errors swamping those of the Doppler itself. Even when all this was done correctly, the system remained a dead-reckoning one, that is, it could not provide an independent fix relative to the ground, and like all such systems, even inertial ones, it would eventually drift away from true position and need updating by an external fix. It is still true of modern INS although the amount of drift is now so small that an uncorrected position over normal flight durations is adequate for all but the most demanding applications. Since this is a historical paper further details of the engineering practice and basic theory behind Doppler systems will not be given here. Should any reader be interested references are given at (1), (2) and (3).

Early Dopplers were characterised in the UK by Marconi's Green Satin system that was fitted, amongst others, to many of the V-bombers. It was a design based

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

mainly on existing high-power pulse transmission techniques developed in the late 1940's and was therefore a bulky and power-hungry system, weighing some 150 kgs and consuming 500 W of power, not at all suitable for smaller aircraft. However, it demonstrated the usefulness of Doppler for long-range navigation and it was decided to take a look at the possibilities of making a much smaller and lighter system. It was at this point that Decca came into the picture.

2. FIRST DEVELOPMENTS. The trigger for a look at a lightweight Doppler was the fact that because Naval aircraft were then much smaller than those of the RAF, they simply could not carry the standard bulky RAF Dopplers. A contract was offered by the Ministry of Supply to look into the problem and Decca decided to take up the project. Accordingly, Decca formed a Doppler Department in the Autumn of 1954 for the initial task of carrying out a feasibility study for a light-weight Doppler navigational system to a Royal Navy specification which was to be installed in the aircraft that became known as the "Buccaneer". It was, of course, a classified contract, as were all such projects at that time, and since it was the Company's practice to refer to classified contracts in this category by male names so this particular contract was given the internal code name 'Jason'. Whether the Company expected, by entering the Doppler business, to find the Golden Fleece is not known but certainly the project laid the foundation for an activity which proved very stimulating. At the time the work commenced, as already noted, Doppler equipments were based on typical medium power airborne radar techniques involving transmitted peak powers of the order of 10 kW. The aim of the feasibility study was to examine the possibility of developing a system capable of operating with an overall error not exceeding 0·5%, and to assess the probable weight and power requirements of such a system.

It was clear that the initial phase of the work would involve basic engineering effort and so a small team of design engineers was brought together. It included expertise in the general radar area together with specialists in antenna design, microwave design and mechanical engineering. The first problem encountered was that of finding accommodation during a time when the Decca Company as a whole was undergoing rapid expansion. However, after some negotiation a home was found in the Decca Corner House at Shannon Corner, New Malden, on the Kingston bypass and by the good offices of the other Decca departments already established there enough help was obtained to enable the study to be completed on schedule in May 1955. The conclusion reached was that a system capable of meeting the technical specification could be developed within a weight of the order of 60 kg which was considered sufficiently attractive for development work to be authorised immediately. The real activity of the department then commenced and it became necessary to consider the type of organisation necessary to fulfil the development phase of the programme.

Decca's view was that a product oriented department was more flexible than a general development department operating over a broad field and so arrangements were made for the creation of a fully self-sufficient research and development facility together with its own back up services such as drawing office and model shop. This organisation was gradually built up over the second half of 1955 in the space available at Decca Corner House. However, it was fairly obvious that the full facilities required to execute the contract could not be accommodated in the Corner House and so the

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

company obtained additional premises at the new Hersham Trading Estate which were scheduled to be ready for occupation in the spring of 1956.

This period was one of particularly heavy effort in designing the layout of the new premises and generally liaising with the administrative departments responsible. The final move in April 1956 was made during a particularly wet period of weather which caused some embarrassment as the roads through the new estate had not by then been completed. Staff had vivid recollections of transporting expensive equipment through a sea of mud. By late spring the new department was well established in its new quarters and in the latter part of that year experimental hardware began to emerge from the model shop. One of the ways in which it was hoped to reduce substantially the weight of the equipment was by adopting a philosophy of using a very low peak powered transmitter together with a long pulse. The validity of this concept was absolutely fundamental to the project and so the first task was to produce a transmitter-receiver unit so that flight trials could be carried out to assess performance. A suitable experimental system was available in the spring of 1957 and flight trials were carried out in a Valetta aircraft at Defford which was, at that time, the aerodrome associated with the Radar Research Establishment. This establishment later became the Royal Radar Establishment (RRE) after a visit by Her Majesty Queen Elizabeth and the Duke of Edinburgh. A beneficial side-effect of this visit was that the Airborne Doppler Radar Department at RRE, being on the royal itinerary, was redecorated to a standard much higher than that normally associated with government establishments. The ensuing flight trials fully confirmed the validity of the design concept and so work to produce a complete system was instituted. At this stage it was felt that the transistor as a device had arrived at a point in its development where it could be considered out of the experimental stage. Accordingly, proposals were made for basing the entire tracker and computer on the use of transistors, although this rather bold step was initially rather frigidly received by the authorities. However, after a certain amount of discussion and persuasion a major concession was obtained in that Decca was authorised to produce a tracker based on transistors provided that work on a more conventional tracker using valves also proceeded. In the event, the valve version was never taken to a conclusion since the transistor equipment was proved to be perfectly viable before the end of 1957.

3. PRODUCT DEVELOPMENT. During 1958 flight trials with a complete experimental sensor were carried out and achieved results which were highly promising. Work on the analogue computer was proceeding at the same time and by late 1958 a complete development system was ready for flight testing. Again the trials were conducted with no more than normal routine problems and production prototypes were produced in 1959 enabling the equipment to enter service at a time which fully met the required time schedule for the aircraft.

At this time the department was constituted solely as a research and development unit and so the short run initial production of the equipment was carried out in a pilot unit which was a centralised service of the Hersham division of the company. This pilot production established that all the drawings and specifications were satisfactory before the main production was commenced, which was carried out in the Malden Way factory of the Radar Company. It is interesting to note that this equipment, which became known as Decca Doppler Type 60, was still in production 10 years

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

later and was the first Doppler system in the world to have gone into service using transistors for a very high proportion of the circuit functions. Both the accuracy specification and weight figures achieved were in line with the original predictions made in the feasibility study. During 1957 there were strong rumours that Doppler systems were likely to become declassified and released for civil use by the end of that year. As a result of this, commercial airlines and airline organisations began to think in terms of the commercial use of Doppler systems. Towards the end of 1957 a series of meetings was held in the United States under the auspices of the American Airlines Organisations, AEEC and ARINC, at which views were exchanged between airline representatives and representatives of companies engaged in Doppler development. Decca was, of course, fully represented at these meetings. Immediately following this a sub committee of ARINC was formed with the task of producing a Doppler specification. The terms of reference were to arrive at a standard installation format and wiring schedule which would accommodate any Doppler system from any manufacturer. Since the half dozen companies engaged in Doppler development had all approached the problem from different points of view any compatibility of installation requirements was purely coincidental. However the sub committee eventually produced a wiring schedule and installation specification which satisfied all parties without forcing every aircraft to carry too much redundant wiring. This final specification was issued as ARINC Characteristic 540.

4. THE CIVIL DOPPLERS. While this was taking place, Decca decided to carry out a feasibility study of a variant of the military Jason Doppler system that would be compatible with the new civil specification. This requirement was approached by deciding to comply fully with the installation requirements of ARINC 540 at the same time making use as much as possible of the design technique already developed. The major difference between the military Doppler and the civil version centred around the fact that the military system was a completely self contained navigator including its own built in computer whereas the commercial philosophy was to produce a basic Doppler velocity sensor which would be coupled to a separate independent computer. It was also considered that the civil requirement would call for higher values of drift angle than the military system. These differences dictated the use of an antenna stabilised in azimuth in place of the fixed antenna used with the military system and the packaging of the other units of the system in standard ARINC units. A laboratory version of this system was rapidly developed under the type number Doppler 61 and the experimental model of this unit was flown in the company Valetta aircraft in February 1958 – the same aircraft that had been used at Defford for the original Ministry trials, it having, in the meantime, become surplus to Ministry requirements. Disappointingly the first flight of this equipment was completely abortive. This rather disheartened the trials team since all the ground checking had indicated that everything was satisfactory and all the monitoring during the flight indicated normal operation. A post mortem discovered that one of the waveguide junctions was misplaced by 90 degrees, consequently no power whatsoever was reaching the antenna. The fault was soon rectified and the equipment again became airborne this time working well beyond expectations. A programme of trials was then implemented so that the performance of the system could be confirmed and an analogue computer was built which took

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

the Doppler and heading information and drove an adaptation of the Decca Flight Log. The Flight Log was a pictorial mapping display that had been developed for use with the Decca Navigator system then being promoted by a sister company, the Decca Navigator Company. As far as is known, this is the first recorded case of the pictorial presentation of Doppler information and it was only some 10 years later that Decca's competitors began offering such systems.

The next phase of work was concerned with the manufacture of six prototypes of the Type 61 which were used principally for various evaluations. One of these systems was used permanently in the company aircraft in connection with a forward looking integrated navigation research project which was called DIAN (Decca Integrated Airborne Navigation). The object of this work was to examine the possibility of coupling together the Doppler system and the Decca Navigator System so that the very high accuracy of the latter could be used to update the Doppler when in an area of Decca cover. Several papers were given to various societies on this subject round about 1960 and it is thought to have been one of the earliest proposals for the hybrid use of a self contained and an externally referenced navigation system. The simplest arrangement of this type was the use of a Doppler driven pictorial display using a chart overprinted with an appropriate Decca lattice. It was then relatively easy to check position according to Decca by comparing the Decca Decometer readings with the chart lattice and so updating the Doppler derived position. This basic arrangement was never envisaged as a practical system but was used in order to assess the potential of an automatic system. It was evident that such a system would be extremely powerful but it was equally evident that for its implementation a method would be needed of transforming the Decca hyperbolic coordinates into rectilinear cartesian coordinates so as to achieve compatibility between the Decca and Doppler data. Many possible methods of doing this, simple and complex, analogue and digital, were examined and as a result it was concluded that only a digital computer could provide a truly flexible approach. A team of digital computer specialists therefore commenced work and the end-result of their work was the well known Omnitrac digital computer which made possible hybrid systems far beyond those envisaged in the original DIAN concept. It made it possible to use almost any combination of navigation sensors as inputs to the computer which then provided a most probable position in either pictorial or digital form. In addition to this research Decca was also at this time offering for sale the Doppler 61 and pictorial display as a straightforward Doppler navigator and as a result of various evaluations Decca was awarded a contract to fit the Trident aircraft of BEA. During these trials some small criticisms of the equipment had been noted so a minor re-engineering exercise was carried out to deal with these points and the resulting equipment became known as Doppler 62. This system was then exploited as Decca's standard commercial Doppler and was widely used in aircraft of Transport Command of the RAF together with a number of commercial airlines. It was still in production ten years later.

5. THE TSR2 DOPPLER. During 1960 there arose a military requirement for a new tactical strike reconnaissance aircraft which crystallised as the TSR2. Decca made a proposal for a Doppler system for this aircraft and as a result of the marked success of both Doppler 60 and Doppler 62 were awarded the contract. The project involved the development of a Doppler system which would have very

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

high accuracy and would be specifically designed for operation as part of a hybrid Doppler inertial system. Work was carried out in the early 1960's which culminated in the provision of a prototype unit to Boscombe Down which was found to meet all the specified requirements. When TSR 2 was ultimately cancelled the Doppler, known as Type 67 M, was so promising that Decca was instructed to continue with development for future RAF requirements. Some modifications to the basic specification were made by the Ministry to suit it for other aircraft and the modified equipment complying with the new specification became the Doppler element of the navigation system of the original Hawker Siddeley Nimrod aircraft.

6. THE GPI 7. Up to 1962 all the work of the Department had been concerned with the development of Doppler navigation sensors. However, as part of the Doppler 60 project Decca had gained a considerable amount of experience in the techniques required for analogue computers for navigation. When an RAF requirement for an advanced electro-mechanical navigation computer was issued in 1962 Decca was well placed to make a viable proposal based on work already done. The requirements for this unit, to be known as Ground Position Indicator Mark 7, were to compute position in terms of latitude and longitude or grid co-ordinates and also in terms of distance along and across a selected track. In addition continuous calculation of wind was required together with an ability to operate in a reversionary dead-reckoning mode in the event of Doppler failure. In order to meet the requirements for various aircraft types the computer was required to operate interchangeably with two different types of Doppler, two different power supplies and two forms of airspeed input. These requirements were met in full and the first development model of the equipment was produced in a period of sixteen months from the start of the contract. This unit used techniques substantially different in character from those Decca had previously used, being an electro-mechanical unit rather than an electronic unit. This new character of work made it necessary for Decca to add to its facilities by the commissioning of a clean room for the assembly of precision mechanical parts. This computer was produced in substantial quantities and in spite of a very large number of mechanical components surprisingly good reliability was achieved in service. The GPI 7 was used on the long range transport aircraft of the RAF and also came into service with the Royal Australian Air Force.

7. THE DECCA DOPPLER 70 SERIES. The equipment so far discussed formed work carried out during what may be called the first phase of the Decca Avionics Group history. All the work so far described sprang from the initial Jason contract and represented further development of techniques first established in 1955, but by 1963 it was evident that a new forward looking policy was necessary. At that time inertial navigation systems were beginning to reach a developed stage and it was necessary to decide whether there was a requirement for a further generation of Doppler systems or whether inertial systems would reach a reliability and price bracket which would render Doppler systems unsaleable. Decca's sales department accordingly carried out a market survey with the object of determining whether further Doppler development should be carried out and if so what type of equipment should be developed. Their considered opinion, after considerable

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

investigation, was that inertial navigation systems were unlikely to be price competitive with Doppler over the following ten year period and therefore there was a requirement for a further generation of Doppler navigation systems. The emphasis on the Doppler development should be different, however, from that which had previously guided Decca and should be different from that being prosecuted by competitive companies, particularly in the United States and Canada. The conclusions reached as a result of this market research were, in the event, to prove to be of fundamental importance to further Doppler development and laid the foundation for what became the very successful 70 series of Doppler equipment.

This assessment of the market situation yielded two important facts. These were that in some 80% of applications customers were less concerned about obtaining the highest possible accuracy than they were about other aspects of the system and secondly that the helicopter market, a rapidly expanding one, would probably fit Doppler systems in many cases if suitable equipment were available. On the basis of this information a series of design aims was established for the equipment as follows.

- It should be very easy to install, particularly retrospectively, in as wide a range of aircraft as possible.
- It should have the lowest possible weight and volume.
- Reliability should be of the highest order obtainable.
- Cost should be competitive.
- It should be capable of use in either a helicopter or fixed wing aircraft.
- It should have good accuracy but this should not be taken to the limit if the other factors would thereby be compromised, in other words it should be a well balanced design rather than concentrating on only one aspect.

As a result of the establishment of these design aims various engineering assessments were carried out of the possible ways of obtaining the best compromise. A number of senior members of the engineering team considered these problems over a period of several months, but it was in that peculiarly British institution, the local pub, that the design finally crystallised. This came about during the tail end of a lunch session at the Anchor pub in Shepperton one rainy day in 1964. The weather outside was uninviting, the conditions in the Anchor on the other hand were congenial and as most of the members of the team were present the inevitable technical discussions started. Over a period of about an hour and a half sufficient exchange of views took place for a summary to be produced on a sheet of paper of a design thought to be optimum. It is interesting to note that the system ultimately produced varied in no major respect from the design defined at that time. The design philosophy decided upon had the following main features:

- In the interests of ease of installation it was decided that a single unit equipment would be used rather than the more common multi-unit arrangement. The single unit concept was also considered likely to yield advantages in minimising volume and weight.
- The reliability problem was tackled by making a detailed analysis of failure rates in existing equipments and where ever possible designing out offending components. Factors which were expected to lead to high reliability included

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

the use of an entirely solid state design involving only low voltages and the exclusion of all moving parts from the main unit, a philosophy that had become possible owing to the recent development of a solid state microwave source.

- It was considered that in order to offer the best chance of good operation on helicopters in or near the hover the system should be one involving the parallel operation of the three channels necessary so that switching discontinuities would be avoided.
- In the interests of minimising complexity a continuous wave system was selected which had the added advantage that unlike pulsed systems no altitude dependent phenomena existed and furthermore high efficiency could be achieved.

These major decisions having been taken, circuit development commenced with the object of producing a research model of the equipment as rapidly as possible to prove the feasibility of the approach. It was considered prudent, right from the outset, to produce this model in a physical form as close to the proposed final form as possible. A survey of various aircraft types had indicated that a unit not exceeding 18 inches in length should be the target, so 16 inches became the design aim. The first model was therefore produced in a package 16 inches square so that early flying would be carried out with the final antenna aperture. The unit reached a stage fit for flight on the company aircraft by January of 1965 and was mounted on the company's Prince aircraft during that month, the old Valetta having been scrapped after an accident. Initial flying indicated that a working system had been achieved at least within the flight envelope of the Prince and measurements of signal returns were most encouraging when compared with earlier Doppler systems. Having established that the system looked promising as a general purpose Doppler the next move was to transfer it to the company's Bell 47G helicopter in order to assess operation at low speeds and negative speeds. Sufficient work was done with this model to establish that the operational requirements could be met provided certain engineering improvements were incorporated, and the main objective, that of establishing feasibility, was completely achieved. However, this unit was a typical experimental model that suffered from many shortcomings including an abysmally poor operating temperature range. Since the initial flight trials were carried out in the depths of winter this characteristic made pre-heating the equipment before take off with a large hot air blower designed for de-icing aircraft, absolutely essential. However in spite of such shortcomings the unit gave sterling service in establishing to a very high degree of confidence that the design philosophy was viable. It was well known to Decca at that time that the major Doppler efforts across the Atlantic were aimed at very high accuracy systems to be used as components of hybrid helicopter navigation systems. This approach necessitated fully stabilised antennas and special techniques involving considerable complexity in order to make the calibration of the system independent of terrain. These competitive systems were aimed at producing very high accuracy with little regard to a number of other factors which Decca considered highly important. It was an approach at direct variance with Decca's own approach and their assessment of this situation was that while the American and Canadian systems were catering for the specialist market Decca would continue its attempts to cater for the mass market. In respect of this difference of approach it is interesting to note that the 70 series Doppler was eventually proven to be as accurate over land as any other

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

system of any type available anywhere, even the extremely expensive American systems. Where the 70 fell down slightly was its performance over water when the change of calibration due to the different reflective properties of a water surface was not automatically compensated but had to be corrected by the operator manually selecting a "sea/land" switch. At the time of conception of the design Decca took into account the possibility of automatic land/sea calibration correction but decided that the considerable additional complexity and cost coupled with the necessity to introduce components which were felt would decrease reliability would not result in a good compromise bearing in mind that the principal market was seen to be low-speed helicopters. In any case, it was considered that under conditions of helicopter operation the effects of water surface movement would be such as to substantially outweigh water calibration errors. In the fixed wing case even with some sea error the system was unlikely to fail to reach the terminal area with an error greater than terminal aids can accommodate – Doppler was after all an en route, not a landing, aid.

8. MILITARY TRIALS. Having demonstrated feasibility the next phase of the work was to produce a number of properly engineered evaluation models. This work commenced in autumn 1965 and by early 1966 these models became available and the first customer evaluation was undertaken in Germany in the spring of 1966. This was a broadly-based helicopter evaluation, Decca Doppler 71 being one of five competitive units evaluated. Considering that this was the first reasonably well engineered equipment of the type surprisingly little trouble was experienced and the evaluation as a whole was considered quite satisfactory. Later that year, August 1966, Decca had the system evaluated by CEV at Bretigny on a Mirage IIIA aircraft, the purpose of the evaluation being in connection with the navigation system for the French Jaguar. To facilitate this Decca entered into a licence agreement with Electronique Marcel Dassault (EMD) and a considerable degree of assistance was obtained from EMD during this trial. In the first phase of the trial from August to October 1966 it became evident that the system was not optimised for fast, high flying aircraft, not surprising in view of the helicopter development background. However, during the winter of 1966/67 a joint programme of engineering work between Decca and EMD was implemented in order to optimise the system for the application. The second phase of the trial, carried out in the spring of 1967 indicated that the system would now meet the requirement and as a result of this trial Doppler Type 72 was selected for the Jaguar. Another result of this trial was to show that Decca's attempt to produce a single equipment which would operate correctly from −50 to +1000 knots had been over-ambitious and so it was decided that the 70 series would consist of two major types, Doppler 71 for helicopters (see Figures 1–3 for an example of the Type 71 fitted to a Puma) and Doppler 72 for fixed wing aircraft. In spite of this, it was arranged that the change from one equipment to the other involved no more that changing a few circuit cards, so that customers with mixed fleets could be offered a highly attractive logistical proposition. This feature of the design was jealously guarded throughout the programme and the claim was that one system could be converted to the other in less than one hour. The next evaluation undertaken was carried out in the Comet IVA aircraft of A&AEE Boscombe Down,

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

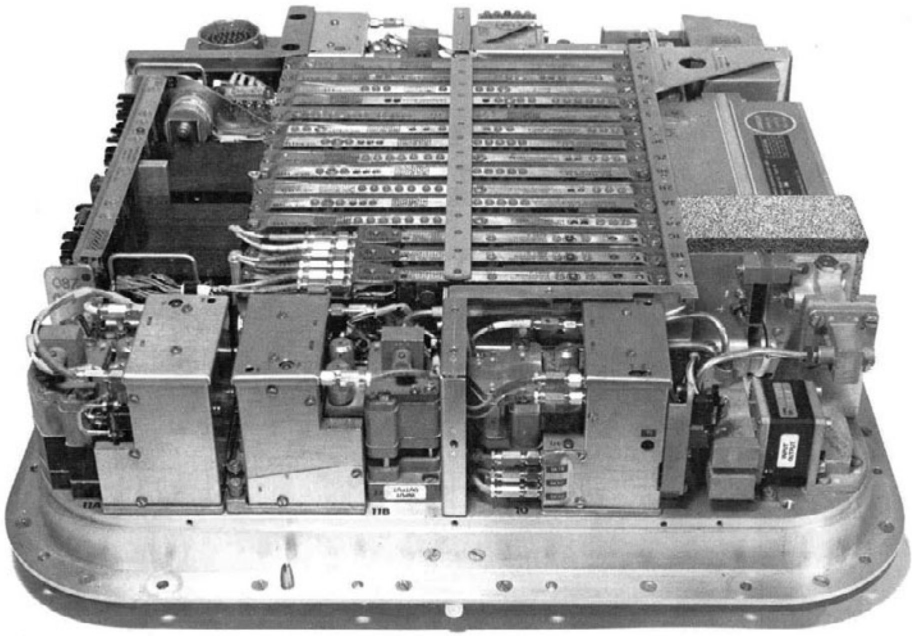

Figure 1. Decca Doppler Type 71 – Antenna/Electronics Unit type 9305.

during the summer of 1967 and can best be described by quoting from the final report.

> "*The performance and accuracy of a prototype model of the Decca Doppler 72 was evaluated over land and sea surfaces. The basic accuracy of the equipment was found to be high, errors in drift and groundspeed being 0·13° and 0·07% standard deviation. The equipment was operated on all flights during the trials period and a total of 103 hours of airborne operation was achieved without any malfunction or failure occurring.*"

9. CIVIL USERS. By the time this trial had been completed design of the production version of the equipment was well advanced, the principal changes introduced being aimed at providing better maintainability and higher reliability under severe environments. The production prototypes of the equipment became available at the end of 1967 and in January 1968 the first production unit was shipped to the United States for evaluation in long haul aircraft operating across the Pacific Ocean (DC8-63F's of Flying Tigers). This was very successful and as a result two major American airlines adopted it as standard throughout their fleets (Flying Tigers and Seaboard World). This type of service was particularly arduous since the climatic conditions varied from high temperature high humidity ground soak conditions (these airlines were primarily flying to/from Vietnam) to conditions at 40,000 feet where the ambient temperature was as low as −60 °C. All the Doppler 70 electronics were mounted on the back of the antenna plate as a single unit which was inserted into the outer aircraft skin and thus did not have the

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

Figure 2. Decca Doppler type 71 fitted to a Puma helicopter.

benefit of fuselage air-conditioning. For the day, a very high utilisation factor was achieved by these airlines, 4000 hours per year being by no means uncommon, and failures of the 70 were rare.

Many other successful evaluations were carried out but only two others will be mentioned. During the latter part of 1967 a prototype equipment had been supplied to the Swedish Marine for evaluation on a Boeing Vertol 107 and in this connection Decca staff paid a visit to Stockholm for a routine meeting just after Christmas. It had been anticipated that it would only be a one night stop but on arrival the Decca representative in Stockholm told them that there would be a second meeting as there might be some Swedish Air Force interest generated by a decision to examine Doppler as a possible subsystem for the SAAB Viggen. It appeared that an Air Board party had flown on the 107 helicopter and had been favourably impressed by the Doppler performance. The meeting was duly held and Decca was formally asked to make proposals for a Doppler system for the Viggen in competition with other Doppler suppliers. They were asked to submit a system for evaluation in a Lansen aircraft at the Swedish Flight Trials Centre during the spring of 1968. By coincidence that was the time at which A&AEE Boscombe Down were carrying out an evaluation of the production version of the equipment on their Comet IVA and by the ready co-operation and help of the Ministry of Technology arrangements were made for members of the Swedish Air Board to participate in this trial. This arrangement enabled the Swedish delegation to become familiar with the equipment and its operation before the commencement of the trial in Sweden and was a good example of

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

Figure 3. TANS (Tactical Air Navigation System) computer 9447D used with the Type 71.

profitable co-operation between the Ministry and Industry. The trial on the Lansen continued through the summer of 1968 with only routine problems and the conclusion was reached that the system would meet the requirement. A special variant of the type 72 was manufactured which was optimised mechanically to suit the Viggen and interfaced so as to be compatible with the Viggen navigation system. It was delivered in August 1968 and remained on the aircraft for a year without attention during which time the full navigation trials of the aircraft were completed. Subsequently the Doppler 72 was fitted on all production aircraft.

10. OTHER APPLICATIONS. The next major milestone occurred when a specification was issued for a Doppler sensor to form part of the hybrid navigation system for the Multi Role Combat Aircraft (MRCA) which later became the Tornado. This was a tri-national project involving UK, Germany and Italy and run by the tri-national company Panavia based in Munich. The competition for this contract was fiercely contested between General Precision of USA, the Marconi Group, and Decca and it was ultimately awarded to Decca. It was a very large project in relation to the resources available particularly as the standard Decca equipment was non-compliant in a number of major respects. A substantial engineering programme was therefore required during which a fully compliant design was achieved. The Tornado project was the largest Doppler

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

Table 1. Types, totals and price of Decca Doppler Systems.

Type (1968)	Number Sold	Approx. Unit Price
Blue Jacket	215	£10,000
Doppler 62	400	£8,750
Doppler 67M	70	£13,500
Doppler 70	400	£6,500

project undertaken by Decca Radar Avionics Department and occupied them for many years.

Following this project, and while Doppler sales were still buoyant, it was decided to take stock and look at future requirements. It was concluded that further large orders for fixed wing applications were problematic but that helicopter requirements were likely to develop for some time ahead. On the strength of this, it was decided to develop a dedicated helicopter system and so was conceived Doppler 80. This was designed as a system of minimum weight with altitude performance being limited to that required for helicopter operations. The principal items of novelty included a much simplified microwave generator and the use of an antenna system based on slotted arrays of printed substrates. This antenna was completely novel and avoided the high costs associated with precision waveguide slotting by using photography and etching techniques. The resulting equipment was the lightest in weight and the lowest in cost of any produced. The series 80 was exported to South Africa and other areas and variants of the design were manufactured by EMD for use on Anglo-French designed helicopters. This was the final development in the Doppler field before the Company changed hands and during this period Decca received Queen's Awards to Industry in respect of Doppler products both for Technical Innovation and for Export Performance. At the end of this period all Doppler radar systems in the British Armed Services were of Decca manufacture and some remained in service at least until 2006.

It is a tribute to the sound basic design of the 70 series that from its conception no less than 30 types of aircraft and helicopters had been fitted with it by 1970 varying in size from the Bell 47G light helicopter to the Douglas DC8-63F large transport. Several very high performance aircraft such as Mirage IIIA, Jaguar and Viggen and the interceptor version of the Tornado in UK, Germany and Italy were also fitted and the extreme flexibility of the equipment was demonstrated by the fact that the 70 series operated correctly throughout the entire flight envelope of all these aircraft types. It is also interesting to note that because security on the system was eventually lifted entirely, the USSR also became purchasers and it is believed that the Dopplers fitted to their helicopter fleet owed much to a study of the Type 71 design.

It is perhaps interesting to note that even as late as 1970 every Doppler Decca ever designed was still in production. The totals sold and the prices paid are shown in Table 1. Ignoring the high accuracy 67 M equipment the reduction in cost over the years of producing Doppler equipment is most noticeable, mainly due to the introduction of solid state techniques and the change in the materials/man hours ratio from about 30/70 for Blue Jacket to about 70/30 for the 70 series equipment. Later, after Decca was bought by Racal, further Dopplers were produced under the

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press

type series number 90 but this history is limited to those produced under the Decca name.

REFERENCES

(1). Walker, E. G., (1958) *Factors in the design of Airborne Doppler Navigation Equipment* Marconi's Wireless Telegraph Company, Chelmsford. *Journal Brit. I.R.E., July 1958*

(2) Gray, T. and Moran, M. J., (1958) *Decca Doppler and Airborne Navigation*. Decca Radar Ltd. *British Communications and Electronics, October 1958*

(3) Thorne, T.G. and Billings, J.A. (1959) *The Performance of Doppler Navigation Systems*. Royal Radar Establishment, Great Malvern. *British Communications and Electronics, March 1959*

https://doi.org/10.1017/S0373463307004511 Published online by Cambridge University Press