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Mode S Data Link Trials
10 – 11 January 1989

A. J. Hughes, R. J. Larkin, M. J. Rose, M. F. Worsley (R. S. R. E.)
T. Alcock (A. T. C. E. U.)

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SUMMARY

On Jan 10th and 11th 1989 two flights of the RAE BAC 1-11 were used for a series
of Mode S surveillance and data link experiments. This report describes the data
link experiments only, giving details of the tests performed, results obtained and
subsequent data analysis.

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final or official statement by either the UK Civil Aviation Authority or the Procure-
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1 Introduction

On 10th and 11th January 1989, dedicated flights of the RAE BAC 1-11 were scheduled to assess the coverage of the aircraft's Mode S aerials. The intention was to fly carefully controlled patterns using different aerial connections during different sections of the flights. It was realized that this trial also afforded an ideal first opportunity to test many aspects of the Mode S data link, following the brief initial test of the GICB protocol during a flight of opportunity on 23rd Sept 1988. The VHF emulation, which had already been tested on several occasions since April 1987, would also be used to down-link aircraft derived data.

This report is concerned only with data link aspects of the trials; the surveillance results will be reported elsewhere.

2 Conduct of the Trial

2.1 Communications

M. F. Worsley (RSRE) was present in the aircraft rear cabin throughout both flights to direct the airborne aspects of the data link trials and to instruct the RAE staff particularly in the use of the DLPU (Eurocontrol Airborne Data Link Processor). This training exercise was seen as an important aspect of the trial; it is hoped that eventually flight trials may be possible without RSRE personnel on the aircraft.

The PRODAT data link was also available during the flights to provide an optional alternative route for air-ground messages. In fact, the only use made of PRODAT during the flight was to inform Malvern that the aircraft had taken off. Subsequently, the PRODAT data file for the flight on 11th Jan was supplied to RSRE for comparison purposes.

Voice communication between RSRE and the rear cabin of the 1-11 was maintained throughout both flights using the UHF frequency of 363.90 MHz. This was the first time that this voice link had been operated successfully. We are not sure why earlier attempts were unsuccessful, but suspect that a better ground aerial and operator's head-set have helped considerably. Unfortunately, with the present aerial site, UHF transmission from the ground injects considerable interference into the Mode S receiver channel, temporarily swamping the receiver. An alternative UHF aerial site must be found before further trials.

RSRE was also able to record conventional SSR data from a selected CAA radar. For this trial Clee Hill data was chosen, since the range and bearing to the aircraft was similar to Malvern's. On 10th Jan there was no time stamping on the SSR data, making synchronisation with Mode S data rather difficult. Fortunately, this was remedied in time for the second flight, and a complete set of SSR data was obtained on 11th Jan.

2.2 Flight Plan

The flight plans were nominally identical on both days, with most of the flying done between FL60 and FL250 to the NE of Bedford, some 85 to 95 miles from Malvern. Figure 1 shows the SSR records of the flight path flown on 11th Jan. The labels record the Mode A code, the Mode C height report and the time in seconds after midnight. The upper part of Figure 1 shows the first half of the flight during which the aircraft climbed away from Bedford, giving

intermittent SSR returns until it reached FL250 and turned back towards Bedford. Having returned to the test area a square pattern was then flown with legs of about 10 miles extent both radial and tangential to the Malvern bearing. Having completed two squares at FL250 the aircraft descended at about 2000 ft/min, still flying the square pattern. The rest of the flight is shown in the lower part of Figure 1, where the aircraft completed two further squares at FL60, followed by a climb to FL250 while flying roughly NE towards The Wash. The maximum range from Malvern was then about 165 miles, when the aircraft turned to complete its circuit and then descend to Bedford.

3 Mode S Data Link

3.1 Introduction

The objectives of the Mode S Data Link part of this trial were:-
(1) to perform "end-to-end" tests, between the "ACE" simulator at RSRE and the DLPU in the aircraft, of the GICB, Comm A and Comm B message protocols;
(2) to test the GICB protocol with interrogations generated by the DALAP at ATCEU;
(3) to demonstrate airborne access to a ground database using the VOLMET process in the DALAP.

A significant feature of the Mode S part of the trial was the intermittent coverage obtained. Whenever the aircraft headed east, Mode S surveillance replies were lost, regardless of which aerials were connected on the aircraft. Since the "squares" pattern was being flown most of the time, this meant that periods of continuous cover were rarely more than 3 or 4 minutes long. Furthermore, during these favourable periods, cover was often intermittent, depending on aircraft altitude, aerial connections, banking manoeuvres, etc. Apparently the strongest replies were obtained when the top aerial was used and the aircraft was heading towards Malvern.

The 10th Jan flight was used to determine an acceptable set of experimental procedures, and to make preliminary tests of all message protocols. The majority of results presented here were then obtained during the 11th Jan flight. Because the ACE software was not yet complete, it was decided to test each message protocol separately; the only exception being the Comm A and Air-Initiated Comm B tests which ran simultaneously. It was known at the outset that a fault in the ACE was likely to terminate each test prematurely. However, on most occasions this did not occur until all required data had been obtained.

In the aircraft some difficulties were experienced in operating the Epson printer attached to the DLPU terminal. Firstly, all error messages (which appeared on the VT220 display in inverse video) were ignored by the printer. Secondly, the particular printer available was rather slow and, if left on continuously, severely limited the operation speed of the terminal. The operational procedure used on 11th Jan required careful control of message rates, with the printer being used occasionally for a "screen dump", while error messages were recorded by hand where possible.

3.2 Comm A - Comm B Tests

The intention here was to deliver free text messages in both directions between the DLPU terminal in the aircraft and the ACE. 6-bit character coding was used for all messages. Message lengths corresponding to one, two, three and four segment linked Comm A's and Comm B's were used. In the ground station the extraction of linked AICB's was controlled by the

CDP (Control Data Processor), since the software for the more efficient control by the CMU (Channel Management Unit) is not yet complete.

The (rather trivial) messages sent in both directions are shown in Table 1, in the order in which they were sent. No problems were encountered with the down-link (AICB) messages. With the up-link messages, there were no problems with one, two and three segment messages. With the four segment message, however, a number of errors were indicated by the DLPU. The first error indicated a character counting error in the ACE. When this was circumvented there were still some problems associated with a period of poor Mode S cover before the message was eventually received correctly.

3.3 GICB Tests - RSRE

The intention here was to request a set of three GICB replies on each aerial rotation to provide Aircraft Position, Meteorological Data and Aircraft State Vector. Since synchronisation between the aerial rotation and the interrogation rate was not possible, it was proposed to schedule individual requests at approximately 2 second intervals. Unfortunately, owing to the amount of monitoring software running in the ACE, and other VAX activity, the interrogation rate slowed to one per five seconds at times. However, this test was successfully completed at the first attempt, in which 75 replies were obtained within three and a half minutes before the ACE crashed. During this test the aircraft was initially flying west towards Malvern and then turned and flew the whole of a southbound leg while completing its descent to 6000ft. Subsequent analysis of the surveillance data showed that Mode S cover was almost continuous during this period. No attempt was made to decode or use the data in real time.

A sample of the data obtained after subsequent decoding is listed in Table 2. The first data field in all reports is the time the reply was received at the ACE. The remaining contents of the reports are as follows:-
Position Report (PTN): Latitude; Longitude (East is positive); height (32ft increments).
Meteorological Report (MET): Roll Angle; Altitude Rate; Wind Speed; Wind Bearing; Static Air Temperature; Normal Acceleration.
State Vector Report (STT): Heading; True Air Speed; Altitude Rate; Static Air Temperature; Normal Acceleration.

A detailed comparison was made between the parameter values delivered in reports from Mode S and from the VHF emulation (see below). For each GICB type, pairs of messages were selected where the Mode S and VHF transmissions occurred within two seconds of each other. All parameter values were in excellent agreement, apart from the two exceptions discussed below.

Firstly, the "altitude rate" in the Mode S Met report was consistently a factor of two lower than values obtained from either the Mode S State Vector report, the VHF Met and State Vector reports, or from deductions from successive Mode C height reports. This error has been traced to a mistake in the original GICB definition document (dated 1986). Here the Altitude Rate in the Met Report is incorrectly quoted as having range ±4096 ft/min, whereas the bit-mapping from the ARINC 429 word correctly implies a range of ±8192 ft/min. Apparently, the RAE coding of the VHF data used the incorrect definition, but this was compensated by RSRE making the same error in decoding. The DLPU, however, coded the data correctly, whereas the RSRE decode of the Mode S data was again wrong.

Secondly, the Mode S reports of Static Air Temperature were consistently 0.5 or 1 deg C more positive than corresponding VHF values. This applied equally to the Met and State Vector re-

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ports. RAE Bedford have confirmed that different air-data computers supply this parameter to the VHF and Mode S systems, but it has not been possible to check where the discrepancy arises.

Although in normal operation the DLPU would be unaware of GICB activity, for this exercise the GICB requests were generated by the ACE as part of empty single segment Comm A's. Consequently each interrogation appeared on the DLPU terminal as a "line-feed", so the airborne operators were fully aware of these GICB's.

3.4 GICB Tests - ATCEU

GICB interrogations were scheduled directly from the DALAP at ATCEU, as a preliminary to providing the Meteorological Office with air-derived wind and temperature data. As above, the GICB interrogations were generated in groups of three, but in this case manually. This test was done while the aircraft was at low level and Mode S cover was very intermittent. However, in spite of many "Relinquish" and "Acquisition" situations, 11 replies were received from a total of 24 interrogations. Of the remaining 13 interrogations, 7 were lost due to the poor cover. The rest were lost due to a software error in the ground station whereby some message storage space was inadvertently over-written after a relinquish/acquisition cycle. This has since been rectified. No automatic decoding was available, but subsequent "manual" decoding showed that most data agreed with VHF values. Since this test was done during level flight, the Altitude Rate parameter was not effectively tested. The same small temperature discrepancy was noted as with the ACE-scheduled GICB's.

3.5 VOLMET Tests

The procedure here was to launch PSL-coded AICB's from the DLPU requesting particular VOLMET reports. The database held in the DALAP should then return the requested data in PSL-coded linked Comm A's for display on the DLPU terminal. The first request for Heathrow (EGLL) data provided the expected reply which was correctly decoded by the DLPU. A major problem concerning the coding of QNH had been identified previously and will require a change to the PSL definition. A minor problem concerning the coding of the VOLMET time parameter has been corrected by a DALAP software change. Subsequent requests for Manchester (EGCC) and Gatwick (EGKK) data resulted in error messages appearing at the DLPU terminal. It has since been ascertained that a minor software error in the DALAP had caused an up-link message to be sent which started with a numeric character. The DLPU could not decode this so generated the error message. Finally, Heathrow data was again requested and correctly delivered.

3.6 Ground Station and Level 4 Performance

Much of this exercise relied on correct operation of the interim "Level 4" protocols on the ground links between ACE, DALAP and Ground Station. As far as we are aware none of the problems detected could be attributed to errors on the ground network.

A minor problem arose when the ground station processing crashed. It was subsequently realized that this was associated with the over-writing problem mentioned above, which has now been corrected.

4 VHF Emulation

4.1 Introduction

The VHF emulation of Mode S was run on both days using the same equipment and methods as in previous trials. All received messages were decoded and displayed for real time checks. This provided an almost continuous source of information for all participants in the trial, especially useful when Mode S surveillance was providing only intermittent cover. At the same time all replies were stored in a VAX data file for subsequent analysis. No attempt was made to run either the Wind Model or the VARS display (map display with decoded aircraft data) in real time.

Two minor problems with data recording remained. Firstly, the input interface to the VAX computer occasionally "lost" or garbled a message. This only occurred at times when the ACE was active and was presumably related to the response time of the process reading the VAX input buffer. Secondly, the bit streams of the messages are stored in character format in a VAX file. Occasionally the input bit pattern corresponds to a "control D" character which signifies "end of file" to the subsequent file reading procedures. To overcome this required manual editting of all data files, which was not very satisfactory, but an automatic way of circumventing this problem has since been developed.

On 10th Jan the airborne VHF transmitter was not switched on until the aircraft had climbed to about FL170. Data was then recorded more or less continuously for over an hour until cover was lost at just below FL60 on the final descent near Bedford. On 11th Jan the first replies were obtained at about FL40 during the climb-out from Bedford. Subsequently about two hours of almost continuous data was obtained. One break in data occurred early in the flight as the aircraft was manoeuvring at a range of about 160 miles. Subsequently there were three brief interruptions at low level (6000 ft) at about 90 miles range and one at 25000 ft at 165 miles range, these points being close to the limits of normal radar cover. Finally, replies ceased when the aircraft descended below FL70 near Cambridge.

4.2 Message Schedules

The present ground station software only emulates the GICB (Ground-Initiated Comm B) protocol, interrogating the aircraft with a repeated sequence of four BDS codes, one interrogation every 7 seconds. On 10th Jan the BDS code sequence 2, 4, 5, 6, ... was used, representing Aircraft Identity, Aircraft Position, Meteorological Data, Aircraft State Vector, respectively. On 11th January the Aircraft Identity request was replaced by a second Met request, giving the sequence 5, 4, 5, 6, ... , representing Met Data, Position, Met Data, State Vector, thus doubling the amount of met data. Representative samples of the decoded data recorded on the two days are shown in Tables 3 and 4. Full sets of data are available on request from M. F. Worsley, RSRE.

The first 4 data fields in all messages represent:– Time of Reply; BDS code; Aircraft Height plus 1000 ft (25ft resolution); Report Type. The remaining contents of the reports are as follows:–
Aircraft Identity (ACT).
Position Report (PTN): Latitude; Longitude (East is positive); Height (32ft resolution).
Meteorological Report (MET): Roll Angle; Altitude Rate; Wind Speed; Wind Bearing; Static Air Temperature; Normal Acceleration.
State Vector Report (STT): Heading; True Air Speed; Altitude Rate; Static Air Temperature; Normal Acceleration.

4.3 Wind Data

Wind data was required for three purposes. Firstly, the data recorded during climbs and descents could subsequently be input to the Wind Model for comparison with forecasts and analyses obtainable from the Meteorological Office. This aspect will be reported in more detail subsequently, but representative examples of this analysis are shown in Figures 2 and 3. Figure 2 shows the Wind Model's analysis of wind speed and direction data obtained during a descent from FL250 to FL60 at about 1530 hrs on Jan 10th. The "Bracknell T+12" data represents the Met Office "Fine Mesh" forecast for mid-day at the trial location based on data obtained up to midnight, and was the most up-to-date forecast available for the flight. The "Bracknell T+0" curve represents a subsequent Met Office analysis of all observations up to mid-day; although this was not available at the time of the flight, it represents the best estimate of actual conditions shortly before the flight. It is seen that the Wind Model output differs considerably from both sets of Met Office data; observed wind speeds are up to 15 kts less than forecast, and wind directions are up to 110 deg different. Other Met Office data shows that at mid-day there was a weak trough some 50 miles to the NW of the flight region. The trough was moving to the SE, and the high level winds behind it were northerly. It is likely that this trough had passed through the flight region at some time after mid-day (the validity time of the forecast) and before 1500 hrs (the time of the flight). Figure 3 shows the corresponding data obtained during a descent at about 1145 hrs on Jan 11th when the wind conditions were much more uniform. Although the wind speed scale has been expanded, it is clear that the Met Office and Wind Model data are in much better agreement. The most significant feature is the considerably greater detail present in the Wind Model output. In particular, features that are smoothed out by the coarse vertical resolution of the Met Office grid can be represented un-smoothed by the Wind Model. Similarly, variations with time can also be fully represented.

Secondly, while the aircraft was flying the squares pattern in level flight, the aircraft heading vector pointed at a range of angles relative to the wind vector. By comparing the estimates of wind vector, averaged along each leg of the square, it was hoped that errors in wind measurement, caused by the changing direction of the wind relative to the aircraft heading, could be detected. This of course required that the actual wind vector remained constant over the area of the square and for the duration of that part of the flight. In analysing the data obtained, two further problems emerged. Firstly, it was apparent that the aircraft "wind learning" algorithm only operated when the aircraft bank angle was less than about 5 deg. Secondly, the time constant of this algorithm was thought to be around 2 mins, comparable to the flight time of each leg. The combination of these two effects means that the flight path flown was not well suited for this test. At FL250 the mean wind speed varied from 33.5 kt on the W-bound leg to 30.5 kt on the E-bound leg. This agreed well with the wind-speed gradient deduced from Met office analysis data for noon. At FL60, however, the aircraft data varied from 37.9 kt on the N-bound leg to 33.2 kt on the W-bound leg, whereas the Met Office data showed no significant gradient. The standard deviations of the aircraft data on each leg were calculated and were generally at least 1 kt. However, since there were few data samples and the instrumentation ensured that these were not statistically independent, little significance can be attached to the results.

Thirdly, the wind model requires a value for an input parameter representing the accuracy and reliability of each wind vector observation. Previously a value of 3 kt has been assumed, somewhat arbitrarily, for this parameter. It was hoped that confirmation of this value might be obtained from the standard deviation of wind vector computed around a complete square

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pattern. The standard deviation of all valid wind speed observations taken over a 10 min period was 1.7 kt at FL250 and 2.2 kt at FL60. Similar values were deduced from the variation of apparent wind angle. However, the same considerations as above apply here regarding the appropriateness of the experiment, so it is proposed that 3 kt be retained for the present as the value of this accuracy parameter.

4.4 Position Data

It has been suggested that the aircraft derived position reports could be compared with normal surveillance measurements as a preliminary to ADS work. In this instance we had Mode S surveillance data from our own, uncalibrated, radar, plus conventional SSR data simultaneously recorded from the Clee Hill radar. Figure 4 shows the position estimates from Clee Hill SSR and from the VHF reports during high and low level anti-clockwise circuits of the square pattern. The VHF reports are rather sparse, having been requested at 30 second intervals, but nevertheless show clearly the aircraft position. On the north- and south-bound legs, where the aircraft was flying tangentially to the radar, the excellent agreement between the tracks suggests negligible range error. At FL250 the VHF and SSR plots on both the east- and west-bound legs are consistently separated by up to one third of a mile, indicating an azimuth discrepancy. At FL60 the east-bound leg is further complicated by the weak and intermittent SSR returns, resulting in a worst case azimuth discrepancy of about two thirds of a mile. From these results it appears that data-linked reports of aircraft position could significantly enhance plot accuracy, particularly where SSR returns are weak and sporadic. The absolute accuracy of the two data sources has not been assessed in this case.

4.5 Height Rate Data

Height Rate is an important parameter in altitude tracking. Present trackers derive altitude rate from Mode C reports which are constrained to 100 ft resolution. Figure 5 shows height rate data recorded during the lower part of a descent from FL250 to FL60 via the VHF link, compared with the output from a vertical tracker using Mode C data from the Clee Hill radar. The particular tracker used here (provided by Dr. D. B. Jenkins, RSRE) estimates altitude rate by fitting a cubic spline function to the four most recent Mode C reports; this is apparently more sophisticated than trackers in current operational use. Although the two curves are in broad agreement, it is most significant that the tracker output lags behind the aircraft reports by some 10 to 15 seconds. Furthermore, the aircraft reports appear to contain more fine detail, which would be further enhanced if reports were obtained on each aerial scan. Both these features could have considerable operational significance.

Figure 6 shows the VHF data from the entire descent compared with altitude rates obtained from a "reconstruction" of the vertical profile. This reconstruction fits a cubic spline function to the Clee Hill data with the constraint that accelerations are minimised. In effect it is the smoothest descent profile consistent with the Mode C data, but does not necessarily represent the actual profile flown. Altitude rate is then obtained from the gradient of the fitted function. The generally good agreement between the two curves is pleasing, and it is not surprising that the VHF data contains more detail than the smooth reconstruction.

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5 PRODAT Data

For most of the flight on 11th Jan the PRODAT system was regularly interrogating the aircraft. From about 11:20 onwards this polling was done at approximately 20 second intervals. The only data fields that could be compared directly with Mode S and VHF data were Latitude, Longitude and Flight Level. It was found that the PRODAT and VHF Latitude and Longitude parameters were in excellent agreement, the majority of reports lying within .001 degrees of the average line. On the northbound and southbound legs this represented about 1 second of travel, comparable to known timing uncertainties. The height reports, however, disagreed significantly. With the aircraft level at about 25000 ft the PRODAT values (reported to 10 ft resolution) were obtained over about 25 minutes. These were on average 166 ft higher than the VHF values (25 ft resolution) with a standard deviation of 14 ft. The SSR Mode C data from Clee Hill (100 ft resolution) were consistent with the VHF data. At 6000 ft a similar comparison over 20 minutes gave PRODAT values on average 34 ft higher than VHF values, with 8 ft standard deviation. It has since been deduced that this discrepancy was caused by an incorrect scaling factor in the PRODAT calculations.

6 Conclusions

These two flights have proved extremely useful in furthering Mode S data link activities. The initial tests on 10th Jan were most valuable since they high-lighted many minor problems and enabled detailed planning of experiments for the following day. On 11th Jan we were then able to test all the message protocols available. Many small software errors were detected, mainly in the ACE and DALAP, but in spite of these all tests were successfully completed. No problems were encountered with transponder or DLPU operation. The fact that the Mode S coverage was intermittent provided an excellent test of several aspects that had not been adequately exposed in the previous ground tests. In general, the Level 4 protocols coped very well with this situation. The availability of UHF voice comms was invaluable in providing real-time co-ordination between air and ground; without it many experimental details and opportunities would have been missed. Although no real-time applications processes were run during the flights, the large number of GICB's recorded via the VHF emulation has provided an excellent supply of air-derived data for future off-line applications work. Several examples have been discussed that indicate some of the potential for subsequent exploitation of Mode S data in operational systems. Some discrepancies have been observed between data values down-linked by different means. This has emphasised the importance for ground-based applications of a detailed understanding of the characteristics of aircraft data sources.

GLOSSARY

ACE "ATC Communications Environment" – a communications simulation programme, under development at RSRE.

ADS "Automatic Dependent Surveillance".

AICB "Air-Initiated Comm B" – a Mode S air-to-ground message format.

ARINC "Air Radio Incorporated" – an organization defining avionics standards.

BDS A Mode S data field defining the transponder data buffer being interrogated.

CDP "Control Data Processor" – one of the three processors in the Mode S ground station.

COMM A A Mode S ground-to-air message format, with 56 data bits.

COMM B A Mode S air-to-ground message format, with 56 data bits.

CMU "Channel Management Unit" – the Mode S ground station processor responsible for interrogation scheduling.

DALAP "Data Link Applications Processor" – a Mode S ground data link processor being developed at ATCEU, Hurn.

DLPU "Data Link Processing Unit" – a Mode S airborne data link processor developed at the Technical University, Braunschweig, for Eurocontrol.

GICB "Ground-Initiated Comm B" – a Mode S protocol involving interrogation by the ground station of a specified data buffer in the transponder.

MODE A SSR interrogations for Flight Identity.

MODE C SSR interrogations for Aircraft Altitude.

MODE S "Mode Select" – a form of SSR with extensive message transfer facilities.

PRODAT The European Space Agency experiment in air-ground satellite communications.

PSL "Phrase Source Language" – a language developed at RSRE for compact coding of ATC phrases.

SSR "Secondary Surveillance Radar".

VARS A colour graphics CRT display at RSRE.

VOLMET Reports to aircraft of meteorological conditions around airports.

Single Segment Message:-

1HI

Two Segment Message:-

2TWO SEG

Three Segment Message:-

3THE THREE SEGMENT

Four Segment Message:-

4THE FOUR SEGMENT MESSAGE

TABLE 1

Messages Delivered in COMM A and Air Initiated COMM B Tests, 11 Jan 1989.

```
11:52:59.73  PTN  52.4995N  -0.3076E/W  10464ft
11:56:06.14  MET  0.0deg  -768ft/min  31kt  -146deg  -3.5C  0.00g
11:53:06.32  PTN  52.4982N  -0.3159E/W  10304ft
11:53:06.59  MET  0.0deg  -832ft/min  31kt  -143deg  -3.5C  0.00g
11:53:12.07  STT  -103.89deg  195.5kt  -1664ft/min  -4.0C  0.00g
11:53:12.17  PTN  52.4968N  -0.3227E/W  10144ft
11:53:12.27  MET  -2.8deg  -896ft/min  30kt  -139deg  -3.0C  0.00g
11:53:18.07  STT  -103.54deg  193.0kt  -1728ft/min  -4.0C  -0.25g
11:53:18.17  PTN  52.4954N  -0.3310E/W  9984ft
11:53:18.27  MET  -12.7deg  -1088ft/min  29kt  -137deg  -2.5C  -0.25g
11:53:24.08  PTN  52.4947N  -0.3392E/W  9760ft
11:53:24.79  STT  -107.05deg  193.0kt  -2080ft/min  -4.0C  -0.25g
11:53:24.87  MET  -23.9deg  -1152ft/min  29kt  -137deg  -2.0C  -0.25g
11:53:29.78  STT  -134.12deg  193.0kt  -1952ft/min  -2.0C  0.00g
11:53:35.83  PTN  52.4906N  -0.3522E/W  9280ft
11:53:36.39  MET  -22.5deg  -1024ft/min  28kt  -137deg  -1.5C  0.00g
11:53:36.61  STT  -145.90deg  192.0kt  -1824ft/min  -2.0C  0.00g
11:53:41.89  PTN  52.4872N  -0.3577E/W  9088ft
11:53:41.99  MET  -14.01deg  -960ft/min  27kt  -137deg  -0.5C  0.00g
11:53:47.83  STT  -160.66deg  190.0kt  -1888ft/min  0.0C  -0.25g
11:53:53.88  PTN  52.4748N  -0.3639E/W  8512ft
11:53:59.86  MET  -8.4deg  -1024ft/min  25kt  -137deg  0.5C  -0.25g
11:54:06:11  STT  -170.16deg  189.5kt  -1952ft/min  0.0C  0.00g
11:54:06.21  PTN  52.4659N  -0.3653E/W  8096ft
11:54:11.88  MET  -5.6deg  -1216ft/min  24kt  -135deg  0.0C  0.00g
11:54:17.88  STT  -178.95deg  190.0kt  -2144ft/min  0.0C  0.00g
11:54:24.16  PTN  52.4563N  -0.3639E/W  7648ft
11:54:24.26  MET  -4.2deg  -896ft/min  20kt  -131deg  1.0C  0.00g
11:54:29.88  STT  177.54deg  187.0kt  -1568ft/min  0.0C  -0.25g
11:54:35.93  PTN  52.4405N  -0.3598E/W  7104ft
11:54:41.97  MET  -1.4deg  -768ft/min  20kt  -131deg  1.0C  -0.25g
11:54:48.22  STT  176.31deg  184.0kt  -1472ft/min  0.0C  0.00g
11:54:48.32  PTN  52.4268N  -0.3536E/W  6656ft
11:54:59.93  MET  -1.4deg  -640ft/min  26kt  -135deg  -0.5C  0.00g
11:55:06.12  STT  178.07deg  180.0kt  -1376ft/min  -2.0C  -0.25g
11:55:12.03  PTN  52.4178N  -0.3495E/W  6400ft
11:55:12.43  MET  -1.4deg  -704ft/min  28kt  -137deg  -1.0C  -0.25g
11:55:12.56  STT  178.07deg  180.0kt  -1376ft/min  -2.0C  -0.25g
11:55:12.66  PTN  52.4144N  -0.3481E/W  6272ft
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TABLE 2

A Sample from the Mode S GICB Replies Received on 11th Jan 1989; see
Section 3.3.

```
15:20:50 2 26000ft ACT NUGGET
15:21:00 4 26050ft  PTN 52.3849N -0.3193E/W 25056ft
15:21:05 5 26050ft MET -9.8deg 64ft/min 67kt -6deg -40.0C 0.00g
15:21:11 6 26050ft STT 112.85Deg 259.5Kt -64ft/min -40.0C 0.00g

15:21:19 2 26025ft ACT NUGGET
15:21:25 4 26000ft PTN 52.3656N -0.2685E/W 24992ft
15:21:32 5 25975ft MET -11.3deg -128ft/min 67kt -6deg -39.5C 0.00g
15:21:44 6 25750ft STT 87.71Deg 268.5Kt -1984ft/min -39.5C -0.25g

15:21:46 2 25625ft ACT NUGGET
15:21:53 4 25350ft PTN 52.3588N -0.2156E/W 24352ft
15:22:01 5 25075ft MET -7.0deg -2304ft/min 65kt -6deg -37.5C -0.25g
15:22:07 6 24800ft STT 75.76Deg 274.0Kt -2656ft/min -36.5C -0.25g

15:22:14 2 24475ft ACT NUGGET
15:22:21 4 24175ft PTN 52.3608N -0.1572E/W 23168ft
15:22:29 5 23975ft MET -8.4deg -2176ft/min 62kt 0deg -34.0C -0.25g
15:22:36 6 23725ft STT 65.39Deg 263.5Kt -2048ft/min -33.5C 0.00g

15:22:42 2 23475ft ACT NUGGET
15:22:49 4 23200ft PTN 52.3691N -0.1126E/W 22208ft
15:22:57 5 22925ft MET -12.7deg -2432ft/min 59kt 0deg -31.5C 0.00g
15:23:03 6 22650ft STT 27.77Deg 246.5Kt -2656ft/min -31.0C 0.00g

15:23:10 2 22375ft ACT NUGGET
15:23:24 4 21975ft PTN 52.3952N -0.0851E/W 20992ft
15:23:26 5 21925ft MET -8.4deg -1984ft/min 56kt 0deg -29.5C 0.00g
15:23:32 6 21625ft STT 8.79Deg 229.5Kt -1888ft/min -29.5C 0.00g

15:23:39 2 21400ft ACT NUGGET
15:23:46 4 21175ft PTN 52.4137N -0.0783E/W 20192ft
15:23:54 5 20975ft MET -5.6deg -1792ft/min 51kt -11deg -28.0C 0.00g
15:24:00 6 20750ft STT -3.34Deg 222.0Kt -1824ft/min -27.5C -0.25g

15:24:07 2 20525ft ACT NUGGET
15:24:14 4 20300ft PTN 52.4357N -0.0797E/W 19296ft
15:24:22 5 20075ft MET -2.8deg -1792ft/min 50kt -19deg -26.0C -0.25g
15:24:27 6 19850ft STT -9.67Deg 229.5Kt -1728ft/min -25.5C -0.25g
```

TABLE 3

A Sample from the VHF GICB Replies Received on 10th Jan 1989; see Section 4.2.

```
11:52:48 5 11850ft MET 0.0deg -1984ft/min 30kt -148deg -4.5C 0.00g
11:52:57 4 11550ft PTN 52.5002N -0.3049E/W 10560ft
11:53:04 5 11375ft MET 0.0deg -1536ft/min 31kt -147deg -4.5C 0.00g
11:53:09 6 11200ft STT -104.59Deg 196.0Kt -1664ft/min -4.0C -0.25g

11:53:16 5 11025ft MET -1.4deg -1728ft/min 30kt -140deg -4.0C -0.25g
11:53:23 4 10800ft PTN 52.4947N -0.3358E/W 9792ft
11:53:30 5 10550ft MET -22.5deg -2240ft/min 29kt -137deg -3.0C -0.25g
11:53:37 6 10275ft STT -135.70Deg 193.5Kt -1984ft/min -2.5C 0.00g

11:53:44 5 10050ft MET -16.9deg -1856ft/min 27kt -137deg -1.5C 0.00g
11:53:51 4 9825ft PTN 52.4817N -0.3619E/W 8832ft
11:53:58 5 9600ft MET -9.8deg -1920ft/min 26kt -137deg -0.5C 0.00g
11:54:05 6 9350ft STT -169.63Deg 190.0Kt -1952ft/min -0.5C -0.25g

11:54:12 5 9100ft MET -5.6deg -2176ft/min 24kt -137deg -0.5C -0.25g
11:54:19 4 8825ft PTN 52.4583N -0.3646E/W 7808ft
11:54:26 5 (missing reply)
11:54:33 6 8350ft STT 178.07Deg 190.5Kt -1408ft/min 0.0C 0.00g

11:54:40 5 8175ft MET -2.8deg -1664ft/min 20kt -133deg 0.0C 0.00g
11:54:47 4 8000ft PTN 52.4371N -0.3584E/W 6976ft
11:54:54 5 7825ft MET -1.4deg -1344ft/min 20kt -131deg 0.0C 0.00g
11:55:01 6 7650ft STT 177.01Deg 186.5Kt -1280ft/min -0.5C 0.00g

11:55:08 5 7500ft MET -1.4deg -1408ft/min 27kt -137deg -1.5C 0.00g
11:55:15 4 7325ft PTN 52.4151N -0.3481E/W 6336ft
11:55:22 5 7200ft MET 0.0deg -704ft/min 31kt -134deg -2.0C 0.00g
11:55:29 6 7150ft STT 179.82Deg 176.0Kt -320ft/min -2.0C -0.25g

11:55:36 5 7125ft MET -1.4deg -256ft/min 34kt -132deg -2.0C -0.25g
11:55:43 4 7100ft PTN 52.3952N -0.3399E/W 6112ft
11:55:50 5 7125ft MET -1.4deg 0ft/min 33kt -133deg -2.0C -0.25g
11:55:57 6 7125ft STT -179.47Deg 165.5Kt 64ft/min -2.5C 0.00g

11:56:04 5 7125ft MET 0.0deg 64ft/min 34kt -133deg -2.5C 0.00g
11:56:11 4 7125ft PTN 52.3773N -0.3316E/W 6144ft
11:56:18 5 7125ft MET 0.0deg 0ft/min 34kt -132deg -3.0C 0.00g
11:56:25 6 7125ft STT -179.12Deg 169.5Kt -64ft/min -3.0C -0.25g
```

TABLE 4

A Sample from the VHF GICB Replies Received on 11th Jan 1989; see Section 4.2.

D211
251
40374 4

D211
193
39993 4

D211
250
40829 5

D211
151
39827.8

2637
69
39579 6

2637
40
39339 6

D231
251
45491 7

D231
245
45218 6

D231
197
45028 2

D231
251
46129 7

4533
21
46899.0

D231
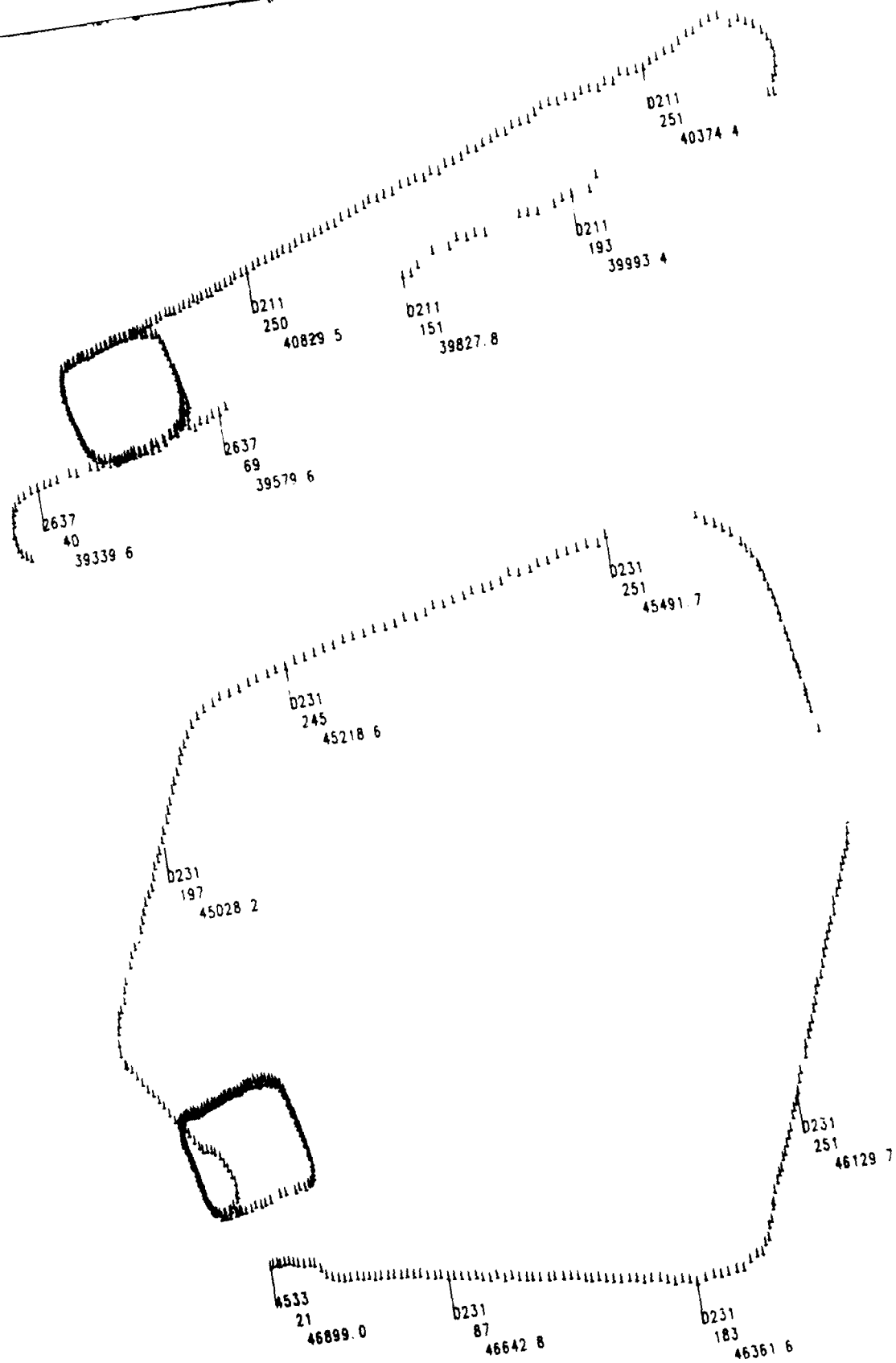87
46642 8

D231
183
46361 6

Figure 1 SSR Records of Flight Path, 11th Jan.
Scale approx. 12 miles per inch.
Upper: Initial climb to FL250, followed by high level "squares" pattern.
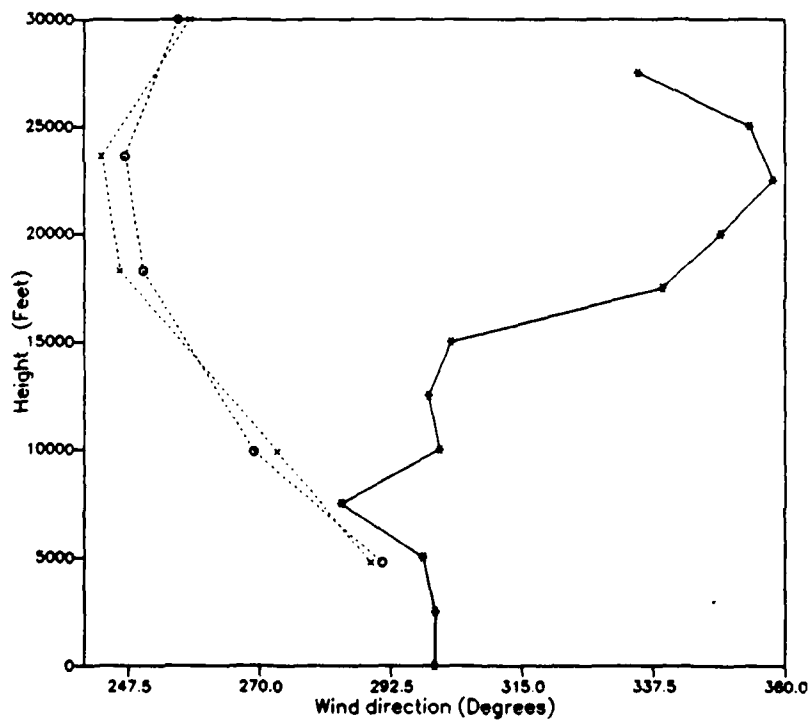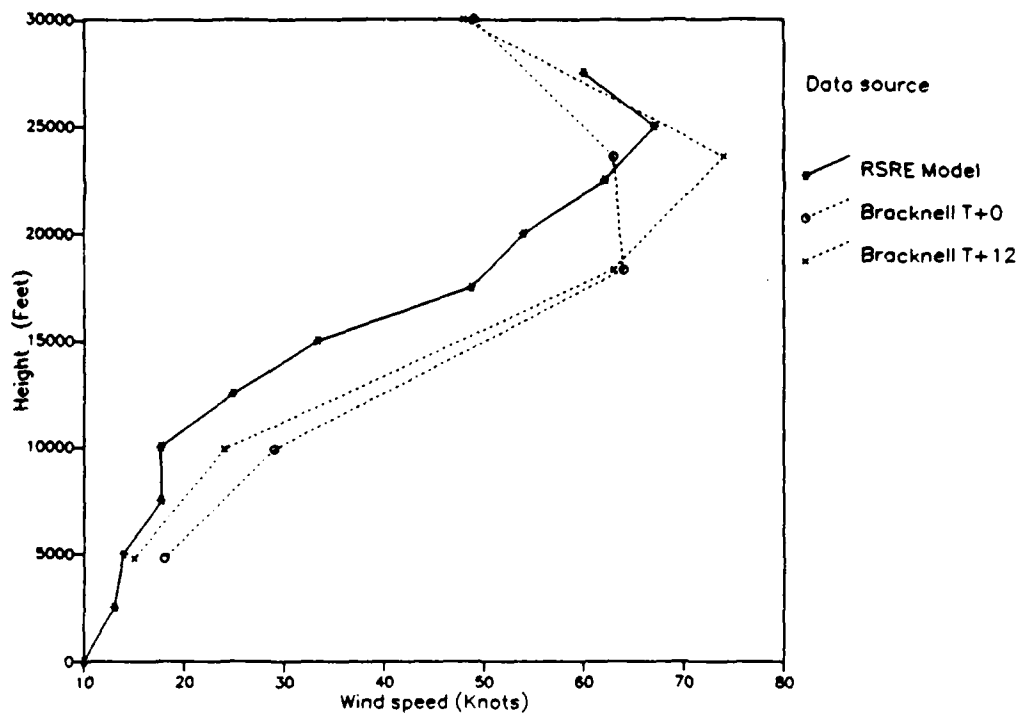**Lower:** Low level "squares" pattern, followed by long range climb and descent.
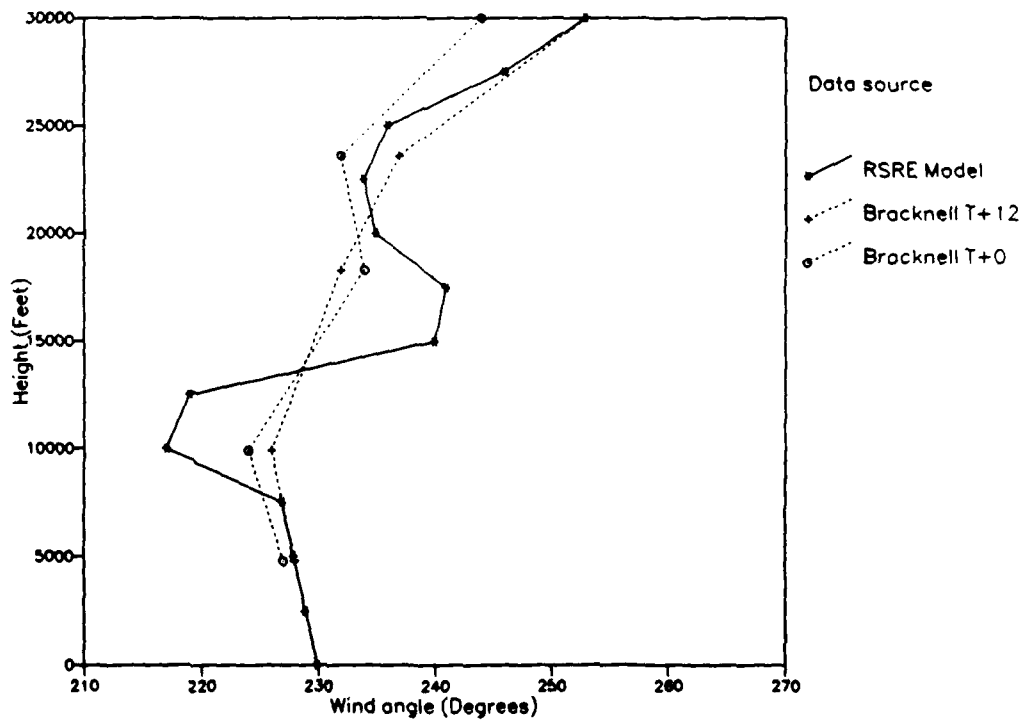
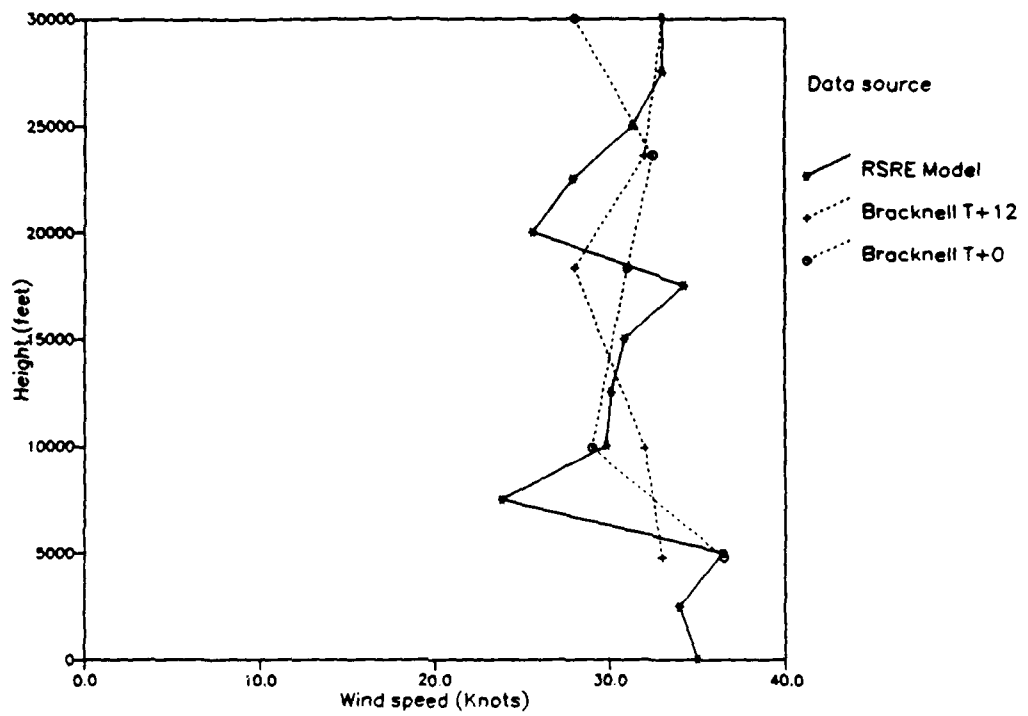**Figure 2** Wind Model Results, 10th Jan 1989, 1500 hrs.

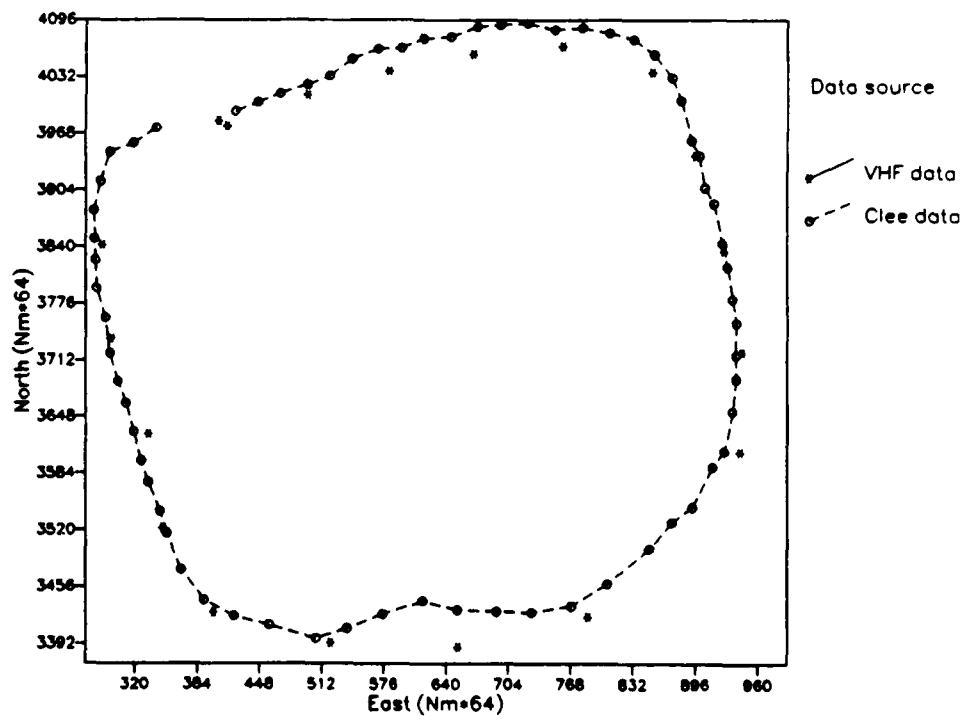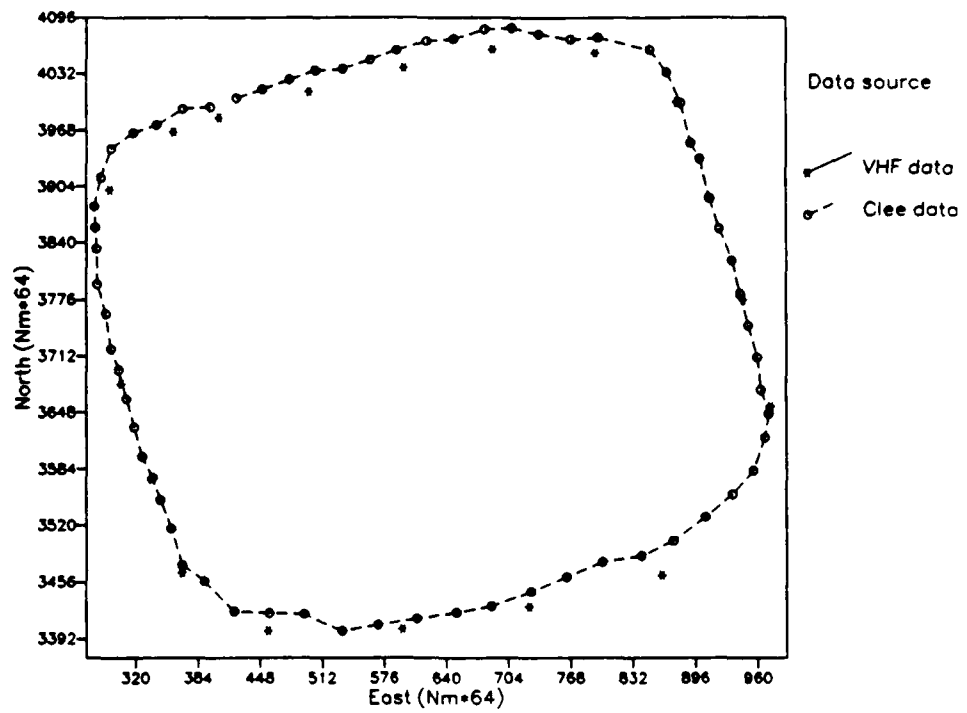**Figure 3** Wind Model Results, 11th Jan 1989, 1145 hrs.

Figure 4 Aircraft tracks, Derived from SSR and VHF, 11th Jan 1989.
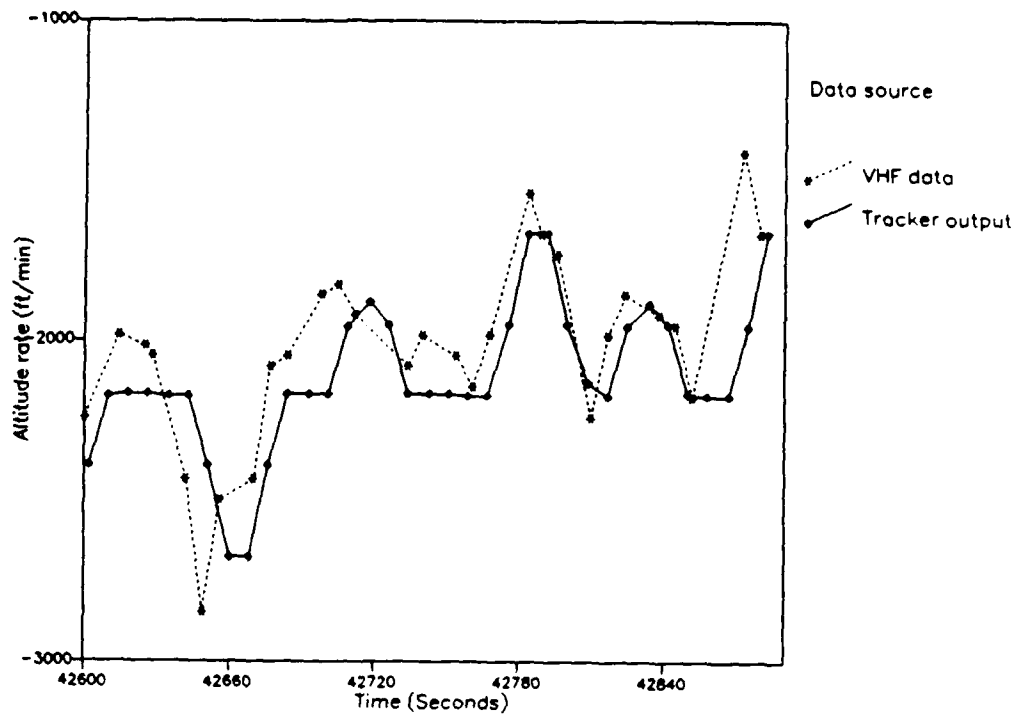**Upper** Data at FL250.
Lower Data at FL60.

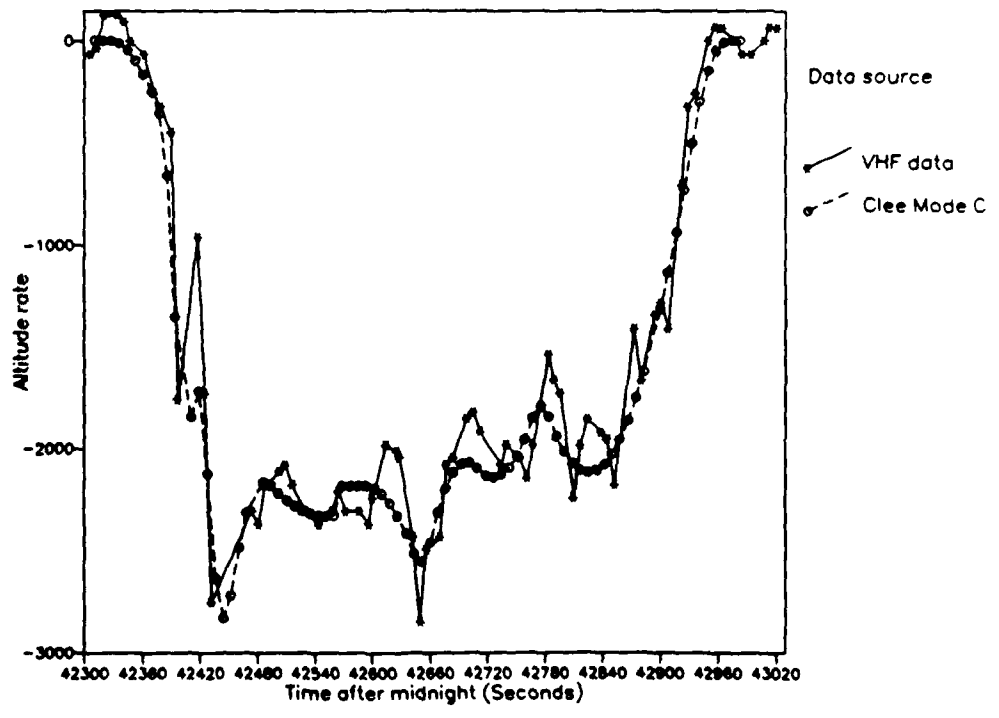**Figure 5** VHF Altitude Rate Reports Compared with SSR Tracker Output.

Figure 6 VHF Altitude Rate Reports Compared with SSR Profile Reconstruction.

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5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
7784000	Royal Signals & Radar Establishment St Andrews Road, Great Malvern, Worcestershire WR14 3PS

5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title
Mode S Data Link Trials 10-11 January 1989

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers)   Title, place and date of conference

8. Author 1 Surname, initials	9(a) Author 2	9(b) Authors 3,4...	10. Date	pp. ref.
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11. Contract Number	12. Period	13. Project	14. Other Reference

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Abstract

  On Jan 10th and 11th 1989 two flights of the RAE BAC 1-11 were used for a
  series of Mode S surveillance and data link experiments. This report
  describes the data link experiments only, giving details of the tests performed
  results obtained and subsequent data analysis.

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