<u>RTCA Special Committee 186, Working Group 3</u>

<u>ADS-B 1090 MOPS, Revision A</u>

<u>Meeting #4</u>

Summary of Final Report on the 1090 Measurements In Frankfurt

Presented by Bill Harman

SUMMARY

The final report on the Extended Squitter measurements in Frankfurt in May last year is now completed. It is currently being printed, for distribution. The report is also available electronically. The testing in Frankfurt included three project aircraft and two ground stations. Several in-service British Airways aircraft were also found to be transmitting Extended Squitters, and these receptions were included in the data analyzed.

Air-to-air performance was tested as well as air-to-ground performance. Reception performance was found to be quite good in most cases, for both air-to-air links and air-to-ground links. Interference measurements were also made in both 1090 MHz and 1030 MHz bands. The results indicate that the 1090 MHz interference in Frankfurt is somewhat higher than the levels recently measured in Los Angeles, although not twice as high. Measurements of aircraft density were also made, and in the report these are compared with corresponding measurements in Los Angeles.

ABSTRACT: The final report on the Extended Squitter measurements in Frankfurt in May last year is now completed. It is currently being printed, for distribution. The report is also available electronically. The testing in Frankfurt included three project aircraft and two ground stations. Several in-service British Airways aircraft were also found to be transmitting Extended Squitters, and these receptions were included in the data analyzed.

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INTRODUCTION

Measurements of Extended Squitter performance were conducted in and around Frankfurt, Germany in May of last year. This was an international effort, including three project aircraft and two ground stations, as illustrated in Figure 1. In addition to the project aircraft, several in-service British Airways aircraft was also observed to be transmitting Extended Squitters. Receptions from the BA aircraft were also recorded and analyzed for evaluating Extended Squitter performance.

Typical flight paths are shown in Figure 2. In most cases, the FAA aircraft, a Boeing 727, “N40” was kept in the immediate Frankfurt area in order to experience the maximum interference. To keep the aircraft near Frankfurt, a repeating oval pattern was flown, shown in more detail in Figure 3. The other two aircraft were flown in more typical enroute paths, extending about 200 nmi to the north in one case, and about 200 nmi to the southeast in the other case (Figure 2).

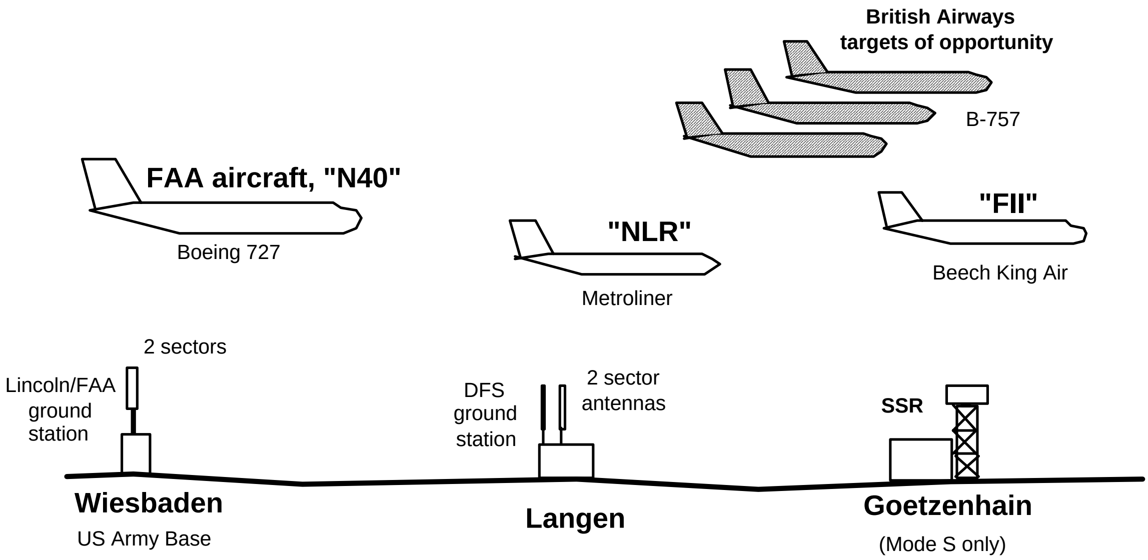

Figure 1. Airborne and Ground Based Facilities in the Tests.

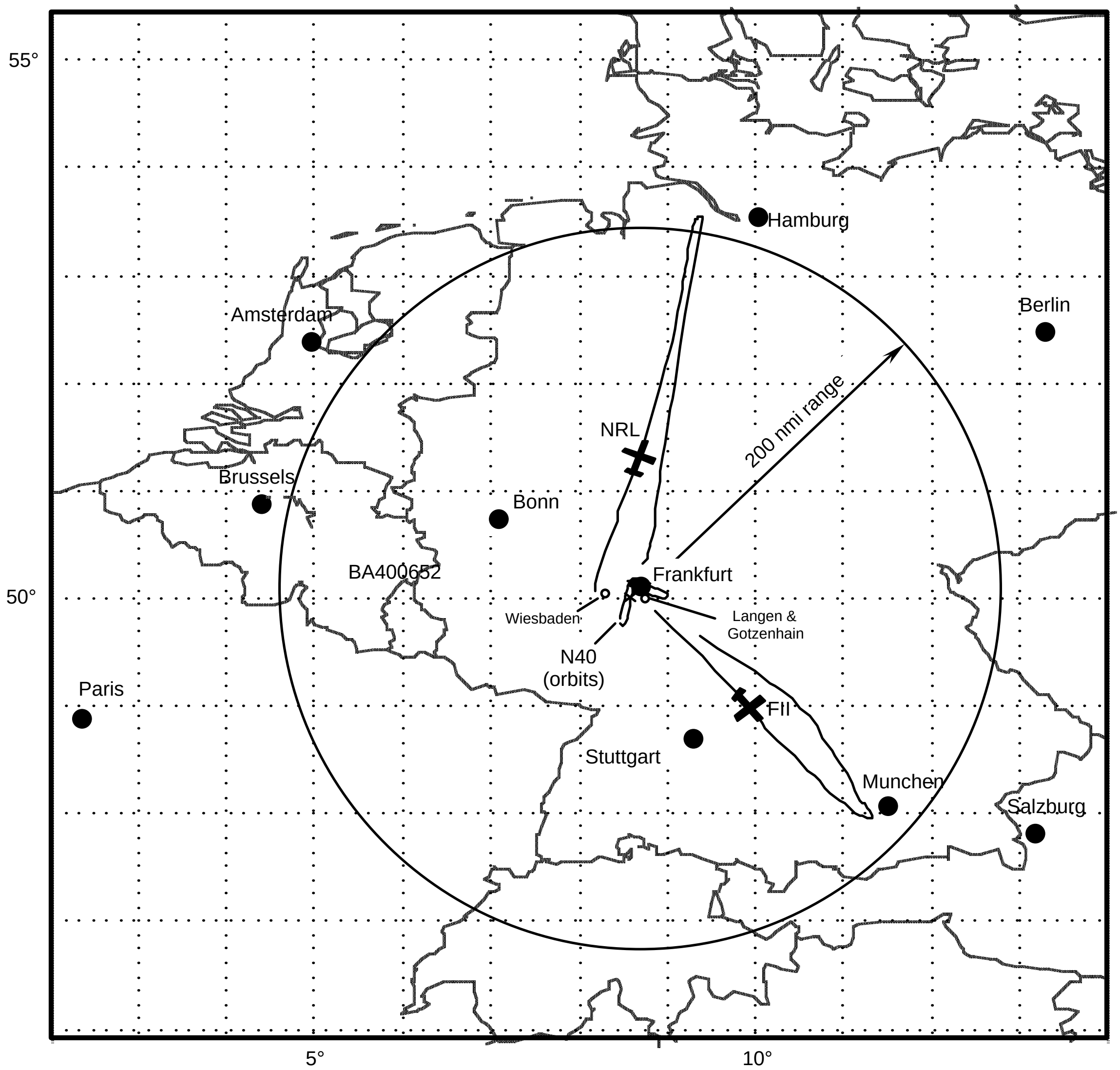

Figure 2. Illustration of the Test Locations Relative to Cities in Central Europe.

Note: *The figure shows flight paths of the project aircraft on 24 May.*

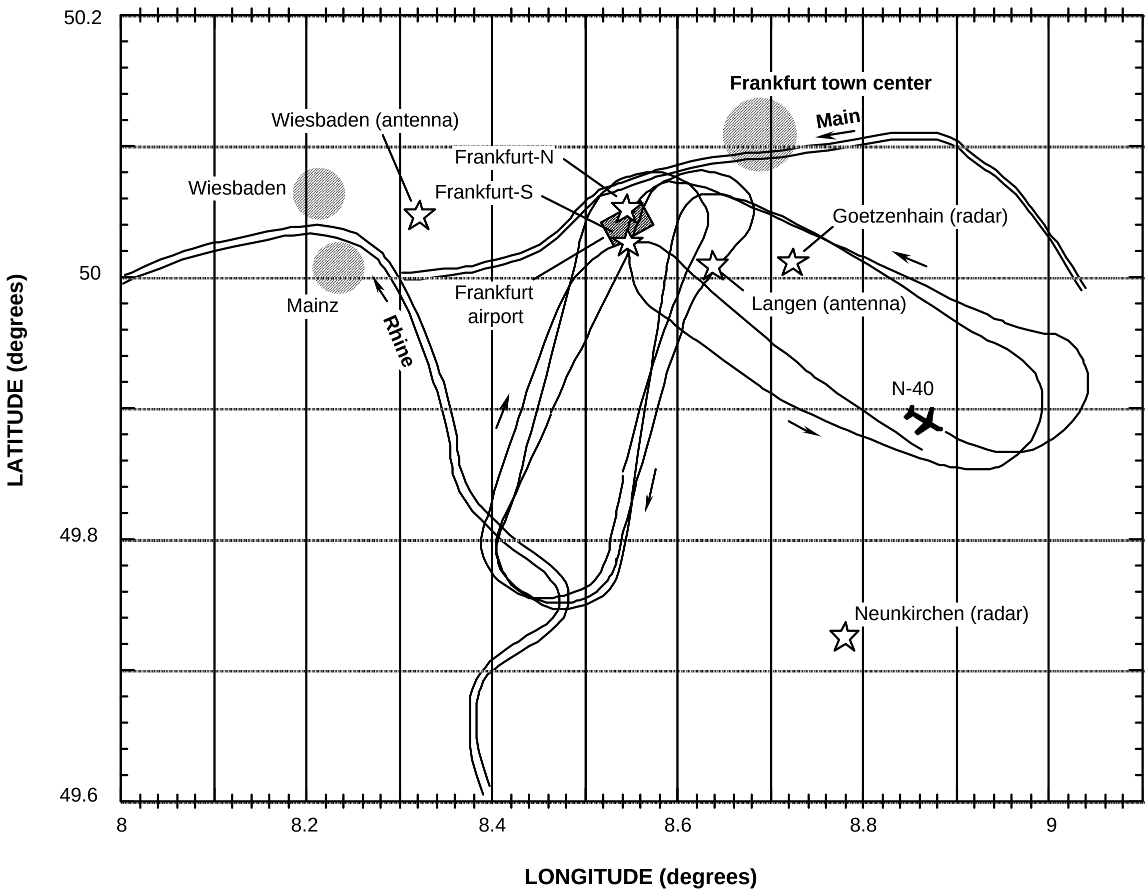

Figure 3. Oval Flight Path of N40, Staying in the Frankfurt High Density Area

Two ground stations were installed, instrumented for Extended Squitter reception and data recording. As illustrated in Figure 3, the two stations were located at Langen and Wiesbaden. At Langen, the receiving antenna was mounted on a rooftop at the German DFS building, The receiving antenna consisted of two 60 degree sectors, which provided partial coverage in azimuth. This configuration is intended to represent two of six sectors, which would cover all azimuth directions. At Wiesbaden, the receiving antenna also consisted of two 60 degree sector antennas, which were mounted on a small tower near the runway at the Wiesbaden US Army Base. In addition to coverage for terminal and enroute airspace, this siting also provided good views of the landing approach for that runway. Data recorded during landings of the project aircraft has been analyzed with respect to Extended Squitter application to runway approach monitoring.

Tests were conducted on five days. The test activities can be summarized as follows (where NLR designates a project aircraft contributed by the Netherlands, and FII designates a project aircraft operated by Flight Inspection International aircraft):

19 May (Friday)	N40
20 May (Saturday)	N40 and NLR
22 May (Monday)	N40, FII
24 May (Wednesday)	N40, NLR, and FII
25 May (Thursday)	N40

RECEPTION PERFORMANCE

Air-to-Air Reception. Air-to-air reception performance was analyzed for a large number of cases. All three project aircraft were equipped for both transmitting and receiving Extended Squitters, so when all three were participating, as was true on 24 May, there were a total of six air-to-air combinations. In addition, British Airways aircraft were included as transmitting aircraft on all of the test days.

On the first test day, 19 May, as N40 was flying in an oval pattern near Frankfurt, a British Airways (BA) aircraft flew directly over Frankfurt at 37,000 feet altitude. The flight paths are illustrated in Figure 4. Receptions on N40 supported a steady surveillance track as the BA aircraft approached from beyond 100 nmi to the west and continued through the point of closest approach (about 10 nmi range), then increasing in range to beyond 100 nmi to the east. The surveillance track was continuous during all of this time. Within 100 nmi, surveillance updates were received consistently (Figure 5), and always within the MASPS standards (12 sec. for ranges beyond 20 nmi and 7 seconds between 10 and 20 nmi).

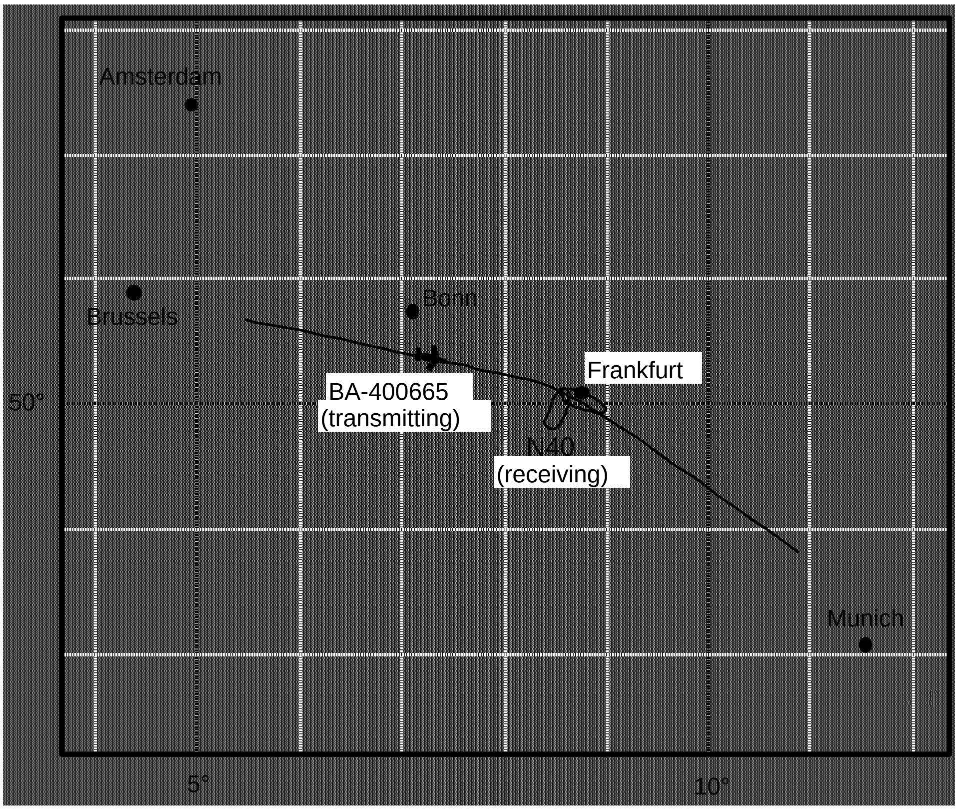

Figure 4. British Airways Aircraft Flying Over Frankfurt on 19 May.

The recorded receptions were also analyzed in more detail to determine whether they would have supported intent communications, although intent messages were not actually transmitted during these tests. The analysis indicates that the MASPS intent standards would be satisfied within 63 nmi during the inbound leg and within 48 nmi during the outbound leg.

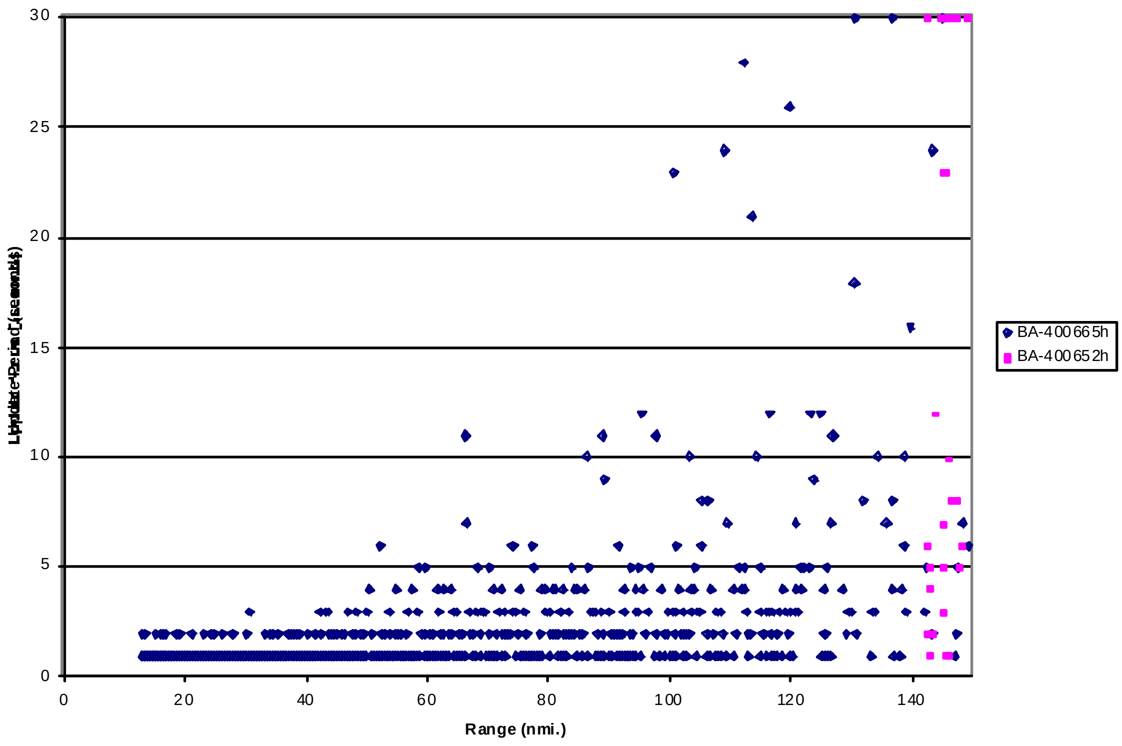

Figure 5. State Vector Update Periods Measured by N40, 19 May

For this one case, the measured performance can be summarized as follows (Extended Squitters transmitted by the British Airways aircraft and received on N40):

	Inbound Leg	Outbound Leg
Surveillance track	continuous within 100 nmi	continuous within 100 nmi
Surveillance updates within MASPS reqts.	met to over 100 nmi	met to over 100 nmi
Intent communication within MASPS reqts.	met to 63 nmi	met to 48 nmi

This is the first case that appears in the recorded data. A large number of other cases were analyzed, and all are presented in the final report.

Air-to-Ground Reception. Air-to-ground reception was also analyzed. This was done for many individual cases, and also was done using the "spaghetti plot" technique.

The spaghetti plot shown in Figure 6 provides a way of assessing Mode S reception performance at Langen based on a large number of operational aircraft flying at the time of the test. All Mode S transponders transmit short squitters, once per second. For each Mode S aircraft, reception of short squitters by the Langen ground station indicates reception quality, although the recorded data does not indicate the location of the aircraft. On the other hand, a Mode S radar can be used to determine the aircraft location and the corresponding 24-bit address. Subsequent analysis of the data recorded both by the radar are the Langen ground station allows this plot to be made. The spaghetti plot is constructed as follows. For each scan of the radar (Goetzenhain Mode S radar used here), a small point is plotted showing the current aircraft location. The Langen receptions are then examined to determine whether short squitters were received from that aircraft during the scan. If not the plotted point is changed to a larger symbol, to indicate a flaw in LDPU reception. Note that only two antenna sectors were being used at Langen, so reception quality should be judged only within these two sectors, as marked in the figure. The results in this figure indicate very good reception quality for nearly every aircraft in the airspace during the time of the test.

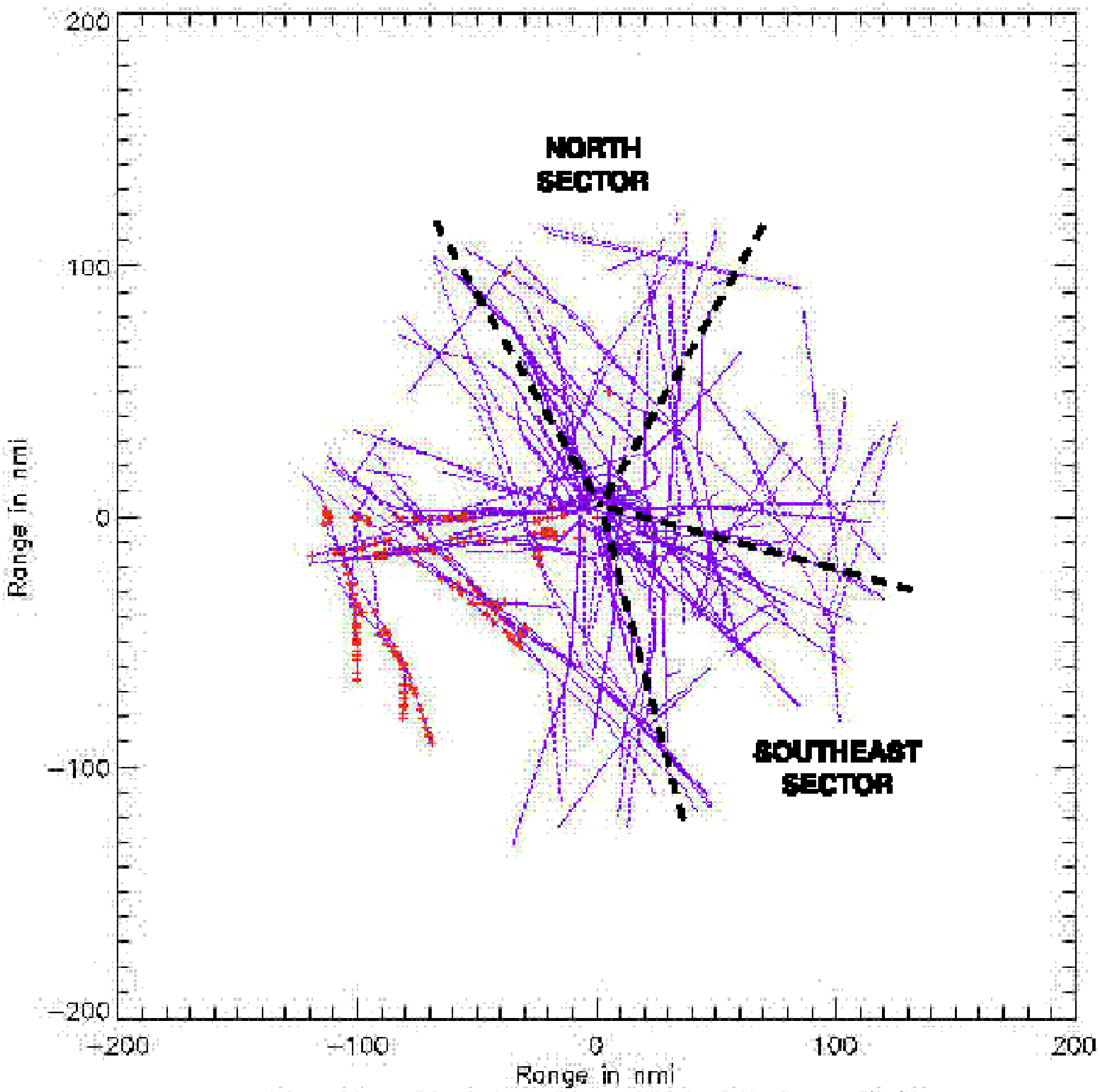

Figure 6. Langen LDPU Short Squitter Plot, 24 May

In order to make the spaghetti plot useful, it was necessary to make quantitative measurements of the horizon conditions seen by the receiving antennas. In preparing for the final report, we went back to both Langen and Wiesbaden in January to make more detailed horizon measurements. The measured horizon values have now been incorporated in the spaghetti plot analysis, producing the results shown in Figure 6.

Runway Approach Surveillance. The Wiesbaden ground station was near the runway at Wiesbaden, and was well sited for runway approach surveillance. The data recorded at Wiesbaden was analyzed with respect to the ADS-B standards for supporting landing approach surveillance. The analysis considered ranges out to 30 nmi or the point at which the aircraft turned onto final approach. The five days of testing included a total of 8 landings at Wiesbaden.

The measurements on the first day are plotted in Figure 7. This is the landing of N40 at the end of the day's testing. During the time period plotted here (924 seconds), the aircraft was under surveillance and in-track the whole time. Also, the Wiesbaden receiving station generated reports consistently once per second with the 3 exceptions shown here. The overall report reliability was therefore 924/927 = 99.7 percent. This is excellent performance.

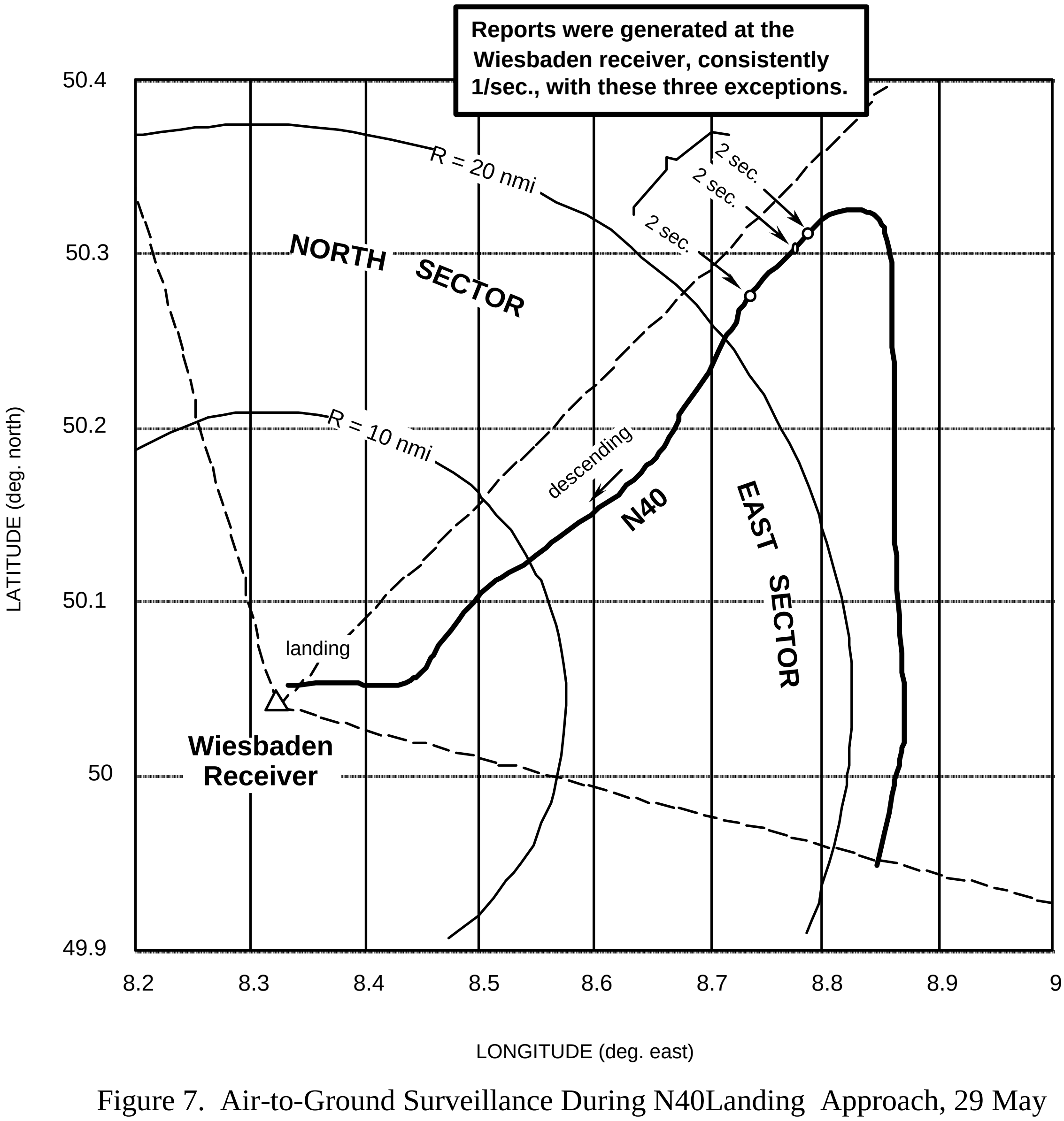

Figure 7. Air-to-Ground Surveillance During N40Landing Approach, 29 May

Note. This plot includes N40's landing and approach and the preceding track while the aircraft was within the receiving antenna sectors. During this time (924 sec.), the Wiesbaden receiving station generated reports consistently 1/sec. with 3 exceptions shown here. Overall report reliability = 99.7 percent.

A similar analysis was applied to all of the eight landings. The results are summarized in the following table. In every case, reception performance satisfied the most demanding standards for landing approach monitoring (for parallel runways, spaced by 1000 feet).

Date	Landing Aircraft	Time in track (%)	No. of Missed Reports	Report Reliability (%)
19 May	N40	100	3	99.7
20 May	N40	100	0	100
20 May	NLR	100	0	100
22 May	N40	100	0	100
22 May	FII	100	1	99.8
24 May	N40	100	0	100
24 May	FII	100	1	99.8
25 May	N40	100	0	100

Gold Standard. The reception performance of the LDPU has been studied in more detail by setting up a comparison against known enhanced reception techniques. This was done by using the detailed RMF recordings as input to a non-real-time processing of certain specific techniques for detecting and demodulating Extended Squitter signals.

Figure 8 shows the results of this comparison. The comparison was made for data recorded during a 6-minute period on 24 May, for receptions on N40 of signals transmitted from the FII aircraft. This period was selected because observed performance was generally poorer than average during that time. TCAS reception techniques are also compared in this figure. The TCAS results shown here were obtained by processing RMF data, rather than using the actual TCAS receiver on the aircraft.

These results indicate that reception performance can, in principle, be increased significantly. Quantitatively, this would extend range from about 35 nmi to about 55 nmi for this particular segment of data.

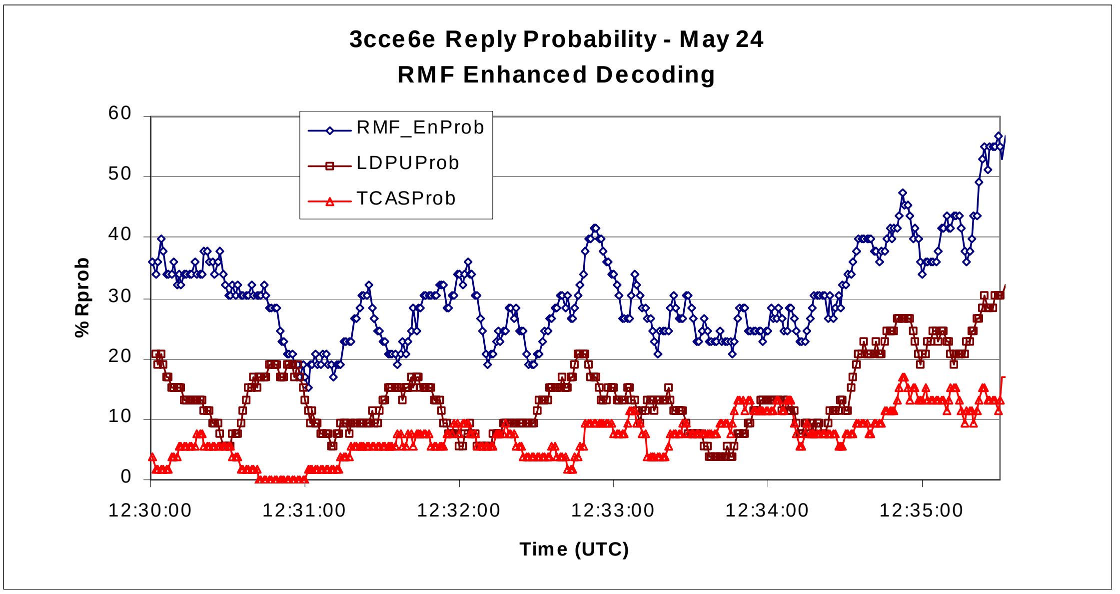

Figure 8. Comparison of LDPU against Enhanced Reception Techniques and TCAS Reception Techniques

MEASURED INTERFERENCE LEVELS

Measurements of the interference environment were made for both 1090 MHz and 1030 MHz bands.

Fruit Rate Measurements. Fruit rate, especially ATCRBS fruit rate, was found to be quite high. Comparing the fruit rate measured in Frankfurt against recent measurements in Los Angeles indicates that Frankfurt is more dense. This comparison is given in Figure 9.

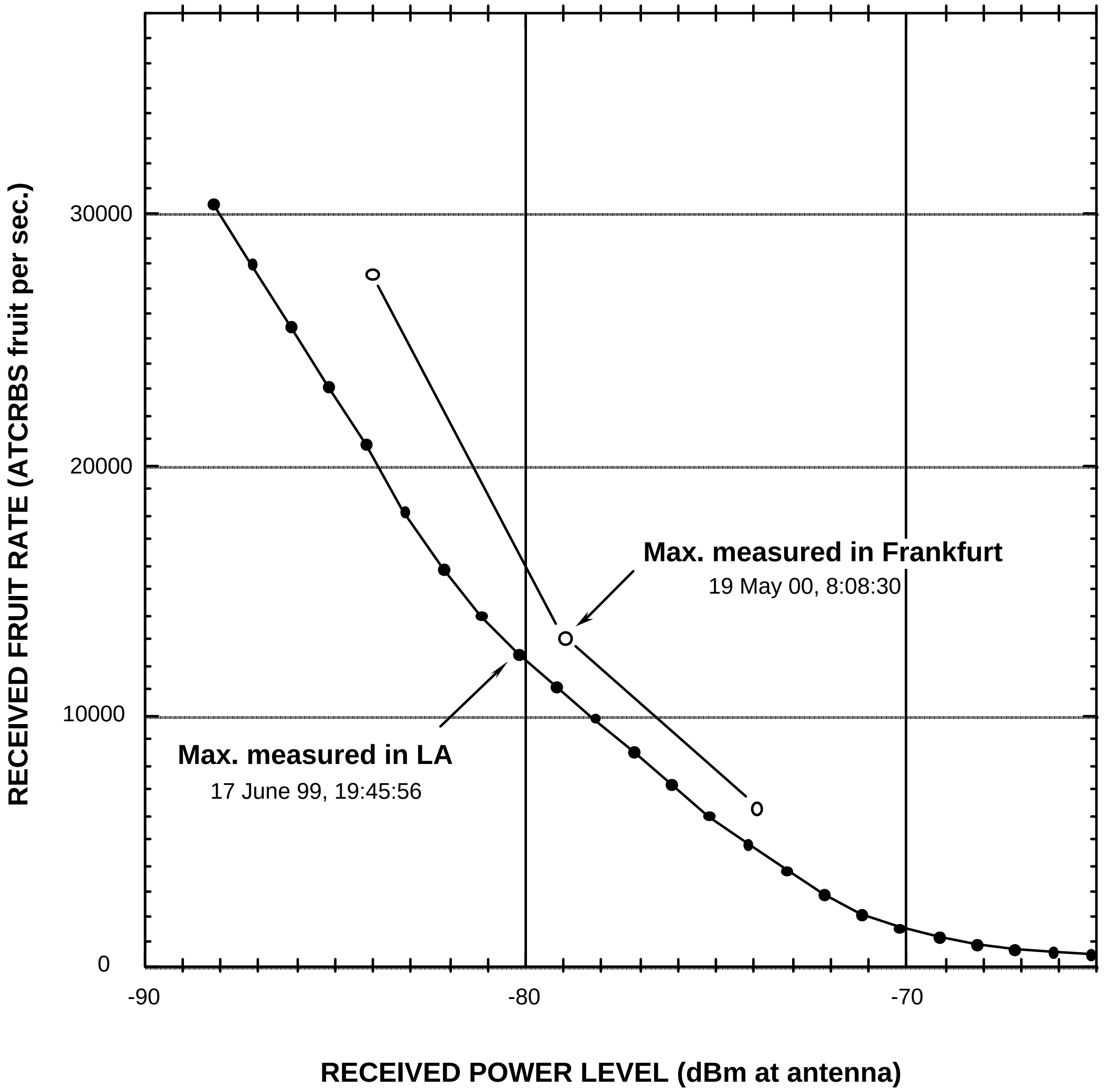

Figure 9. Comparison Between Frankfurt and Los Angeles (Top Antenna).

This difference in fruit distributions appears to be consistent with an observed difference in aircraft distributions. Looking at the measured aircraft distributions in range, Los Angeles exhibits a very high density of aircraft at short range, near the city, with much lower density at long range from LA. Frankfurt on the other hand does not exhibit such a high aircraft density near Frankfurt, but the density is maintained at a high level away from the city. This difference in the air traffic distributions would be expected to cause the fruit distributions to differ, qualitatively, in the manner seen in the figure above.

Interrogation Rates. Interrogation rate measurements revealed a high interrogation rate, especially in the immediate Frankfurt area. It was also seen that ATCRBS interrogation rate is a function of altitude, exhibiting a significant increase as altitude increases. This relationship is shown in Figure 10.

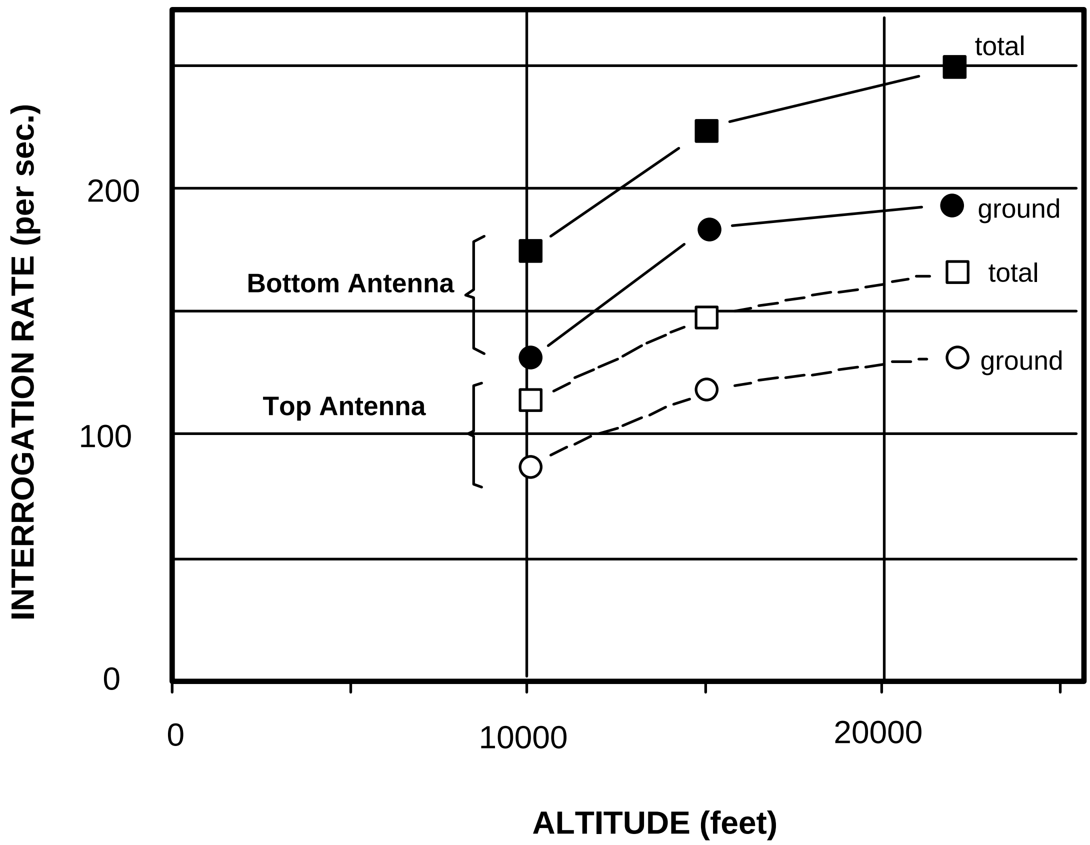

Figure 10. Interrogation Rate as a Function of Altitude

Aircraft Density. Figure 11 shows the number of aircraft and the range distribution relative to Frankfurt. The aircraft distribution in Germany was measured in two ways as shown here. In one case, multiple radars were used together in order to include all aircraft, including those that would be beyond line of sight from a single radar as shown in the plot marked "Multiple SSR Data.". The plotted data marked “Neunkirchen” was derived from a single radar, located at Neunkirchen, and in this case the center point is at Neunkirchen, which is about 20 nmi south of Frankfurt. The number of aircraft as counted using multiple radars is shown for three time on 24 May. These times are intended to show the maximum, the minimum, and a mid-range value, during the time period of the test.

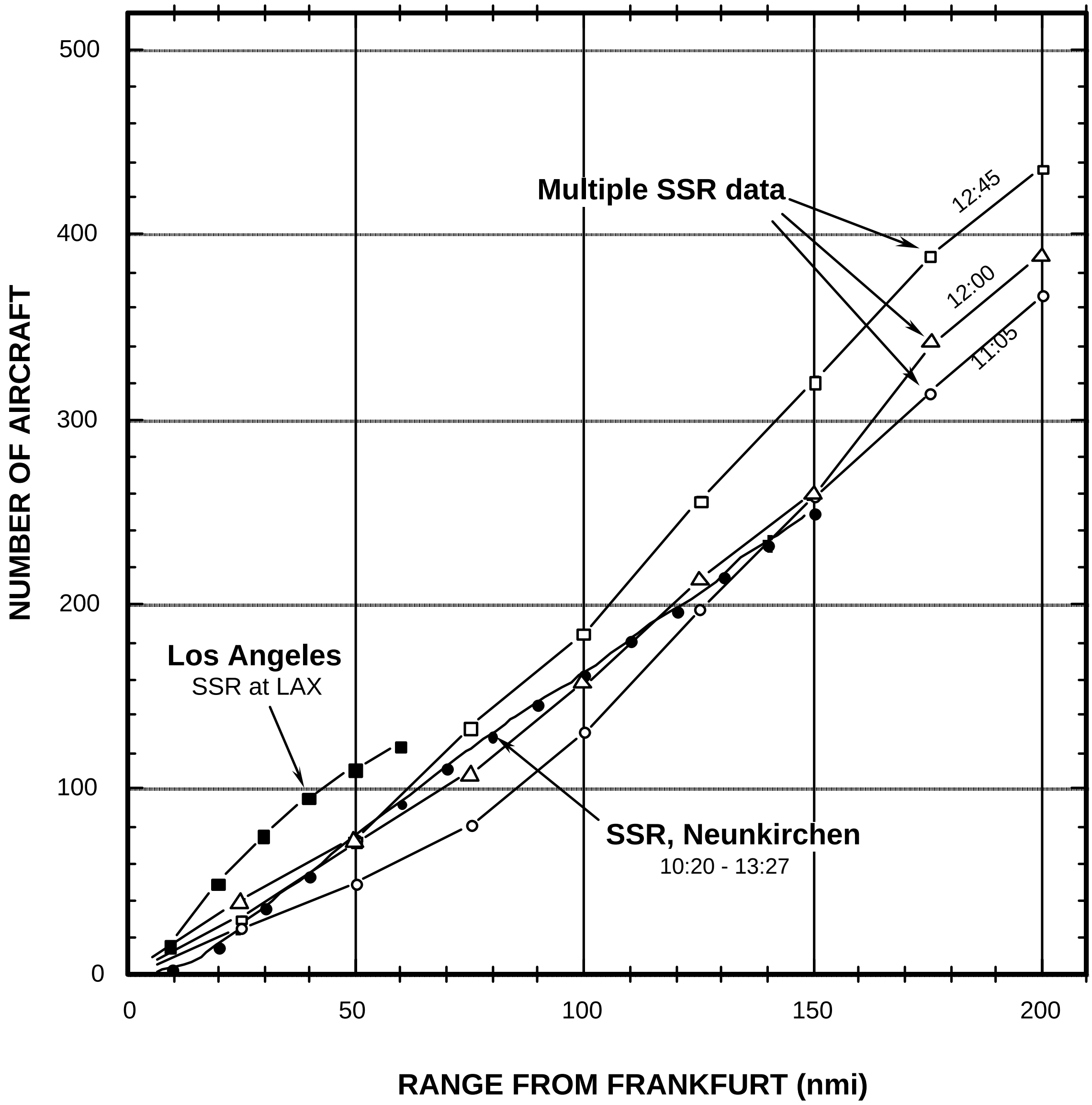

Figure 11. Aircraft Count and Distribution in Range, 24 May

Aircraft traffic as measured by ground based radars was also analyzed to determine the altitude distribution. Figure 4.3.3-3a shows the altitude distribution of aircraft obtained from the multi-radar surveillance of all aircraft within 100 nmi of Frankfurt. The results are shown in both histogram and cumulative forms.

Use of the multi-radar data base provides good coverage around Frankfurt and throughout most of Germany, but eventually a point is reached beyond which radar surveillance does not include low-altitude aircraft. To minimize such line-of-sight limits, this analysis was applied to aircraft within 100 nmi of Frankfurt.

The results in Figure 12 indicate that altitudes between zero and 10,000 feet are the most common. Higher altitude aircraft are approximately uniformly distributed between 10,000 and 40,000 feet. Above 30,000 feet, the distribution is seen to be concentrated at the odd thousands, which is consistent with our understanding of the air traffic control practices in Europe. The median altitude is seen to be about 11,000 feet. This is significantly different from the altitude distribution in Los Angeles, where the median altitude was measured to be about 4000 feet.

Percent Mode S and TCAS. The recorded radar data was also used to estimate the percentage of aircraft that are equipped with Mode S transponders, and the TCAS percentage. The results indicate that of all transponder equipped aircraft, approximately 53 percent have Mode S transponders while the remaining 47 percent have ATCRBS transponders. Also, among Mode S aircraft, approximately 81 percent were equipped with TCAS.

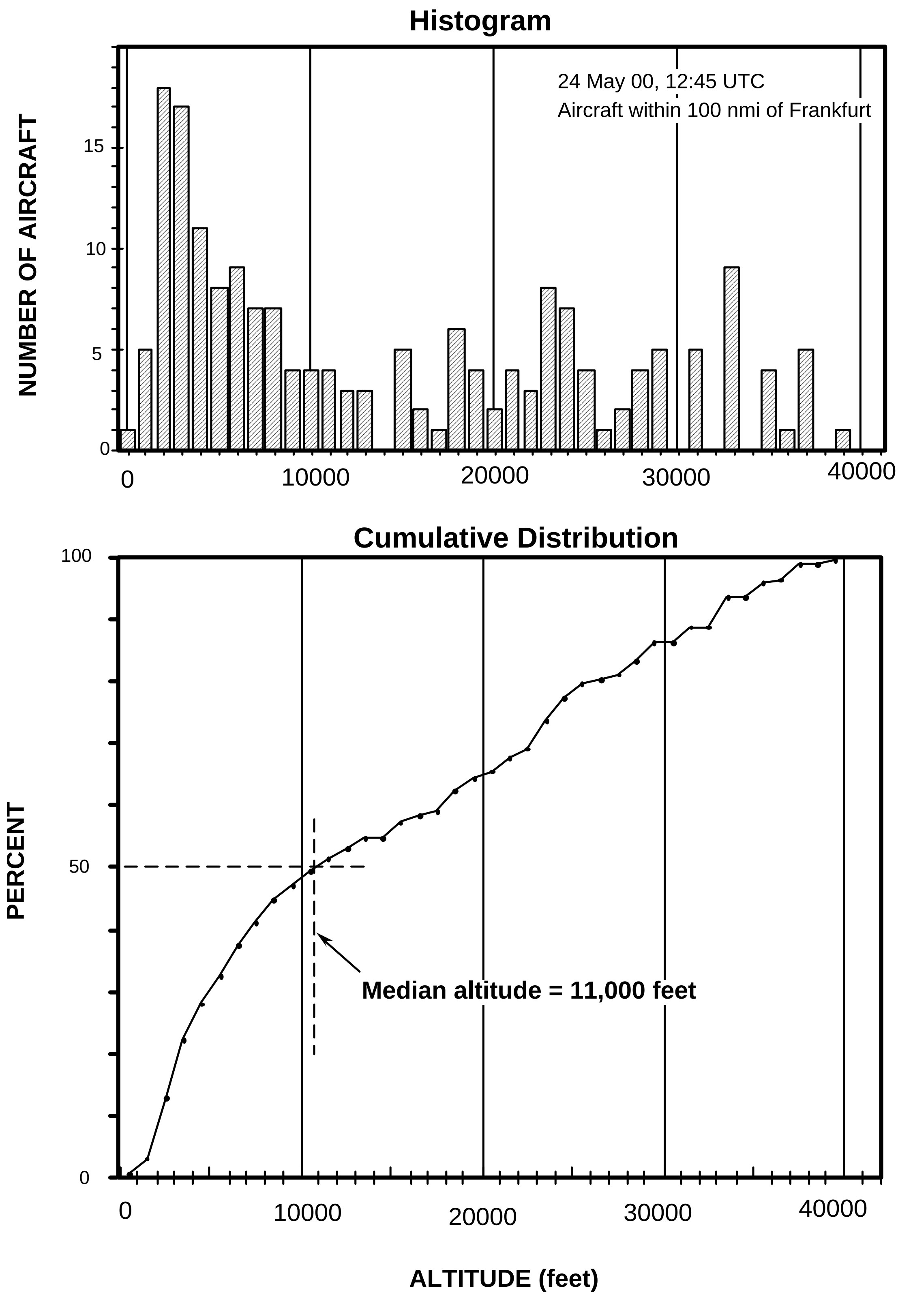

Figure 12. Aircraft Altitude Distribution