UAT-WP-3-17
2 April 2001

RTCA Special Committee 186, Working Group 5

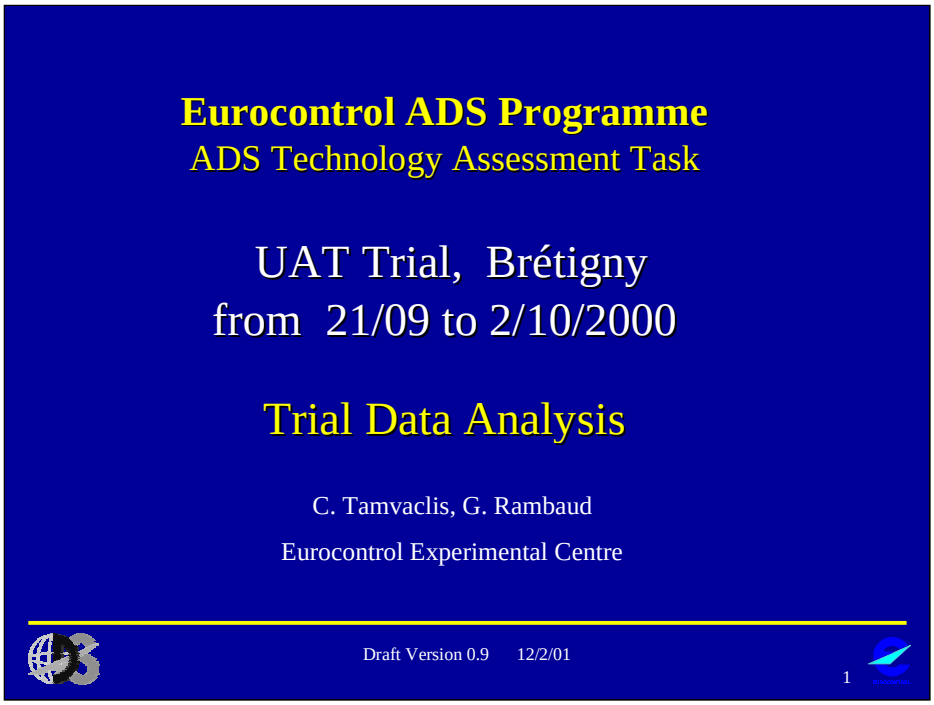
ADS-B UAT MOPS

Meeting #3

Eurocontrol ADS Programme, ADS Technology Assessment Task
UAT Bretigny Trial Data Analysis

Presented by Constantine Tamvaclis

SUMMARY



The Eurocontrol ADS Programme (see web page www.eurocontrol.be/projects/ads) aims towards the harmonised implementation of ADS(-B) and TIS(-B) infrastructure in Europe.

Eurocontrol ADS Programme Manager is Pieter van der Kraan (pieter.van-der-kraan@eurocontrol.be)

One of the of tasks the Eurocontrol ADS Programme is the ADS Technology Assessment Task (see web page www.eurocontrol.fr/projects/ads). This task involves a technical evaluation of the candidate ADS-B and TIS-B datalink technologies, which will serve as an input to the technology decision process within ECAC.

Point of contact for the ADS Technology Assessment Task activities is:

Dr Constantine Tamvaclis,
ADS Studies and Trials Project Manager,
Eurocontrol Experimental Centre,
B.P. 15, Brétigny-sur-Orge,
France, 91222
tel. +33 1 69887419
fax +33 1 69887333
email: constantine.tamvaclis@eurocontrol.fr

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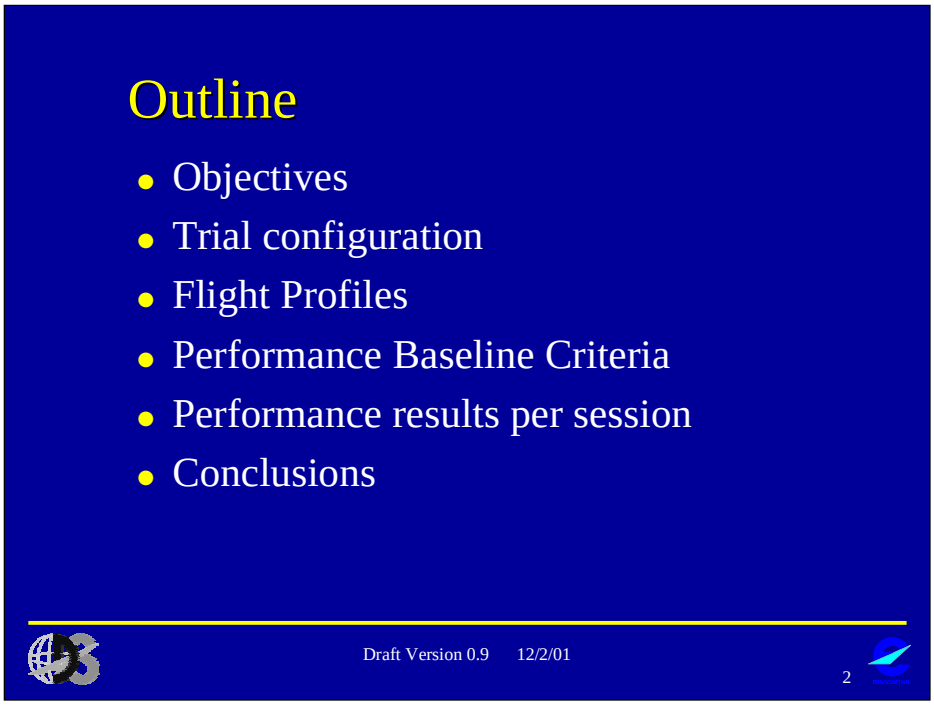

Since 1999. the ADS Technology Assessment Task has been conducting flight trials and simulations on all three ADS-B candidate technologies. This work will continue in 2001. The UAT trial was one of the trials organised in the context of the ADS Technology Assessment.

In 2000, the Eurocontrol ADS Programme together with the FAA Safe Flight 21 Program formed a joint group called Technical Link Assessment Team (TLAT) to produce a technical evaluation of the three ADS-B technologies taking into account data from trials and simulations. The TLAT was co-chaired by Ann Tedford (FAA) and C. Tamvaclis. The results of the ADS Technology Assessment Task trial and simulation activities were fed into the TLAT work. The TLAT report will be published in April 2001.

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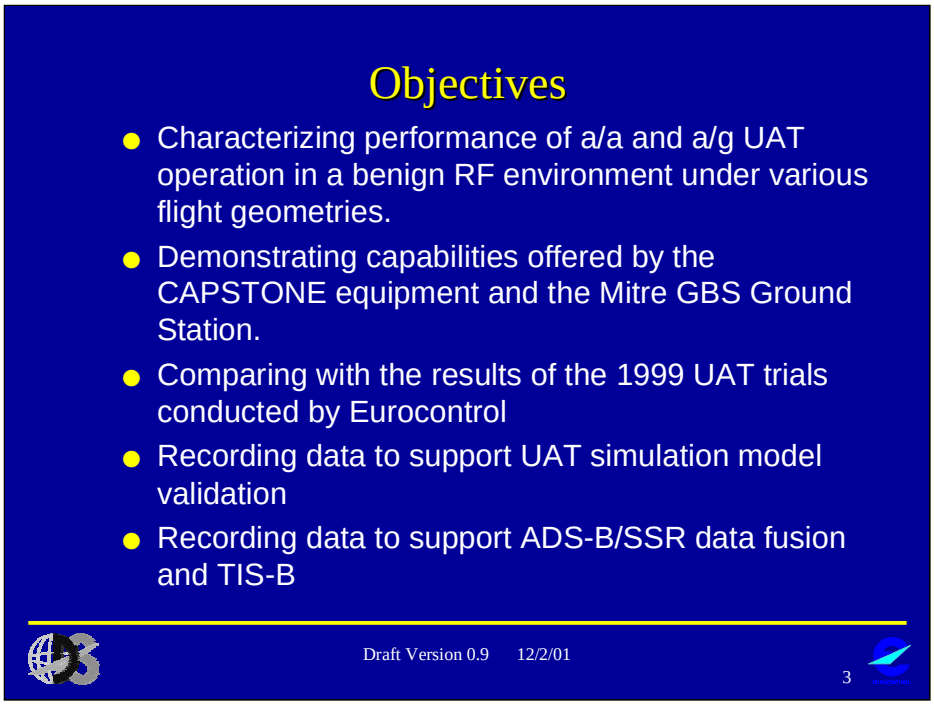

In 1999 and 2000 the Eurocontrol ADS Programme organised flight trials of UAT, VDL Mode 4, and 1090 MHz Extended Squitter.

In 1999 two series of flight trials were conducted for each technology, all of them held at Brétigny. The UAT trials were held in October and December 1999. The UAT equipment used consisted of UPS-AT LDPUs. Trial reports can be found in the ADS Programme web page.

In 2000 three flight trials were organised, one for each technology. In the case of 1090, the trial was held in Frankfurt. An interim report has been published in December 2000. The VDL-4 trial was held in the Netherlands. The trial report is still under development.

The model used for UAT simulations has been developed by the Johns Hopkins University APL team participating in the TLAT. The aim of the UAT simulations is to evaluate performance under various air traffic conditions.

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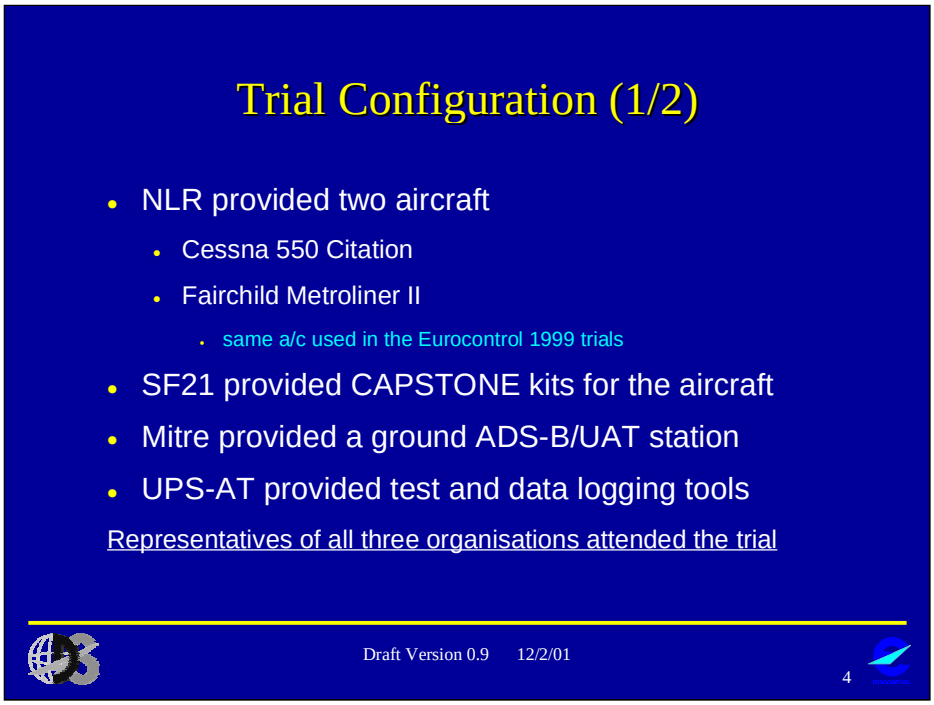
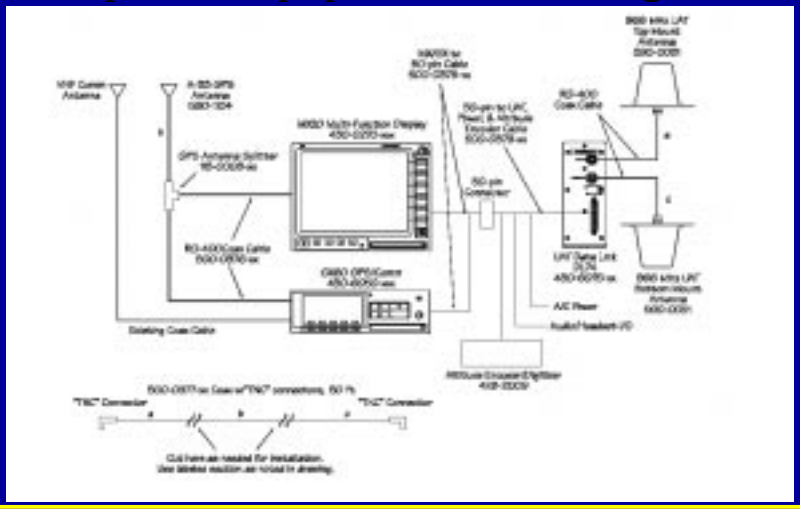


The CAPSTONE kit consisted of a UAT radio transceiver, MX20 display, and GX60 GPS/VHF communications unit, plus one A-33 GPS antenna and two L-Band avionics blade omni antennas (AT-130).

The CAPSTONE kit is designed to provide A1 class ADS-B capabilities.

The Mitre GBS provides also ground to air uplink capabilities which could be used to demonstrate TIS-B and FIS-B services.

Capstone Equipment Block Diagram



Aircraft installation was done according to this diagram specified in the CAPSTONE installation manual

The GX60 VHF radio capability was not used.

Both the MX20 and the GX60 incorporate a GPS receiver.

Data logging occurred via custom software supplied by UPS-AT running on a portable PC.

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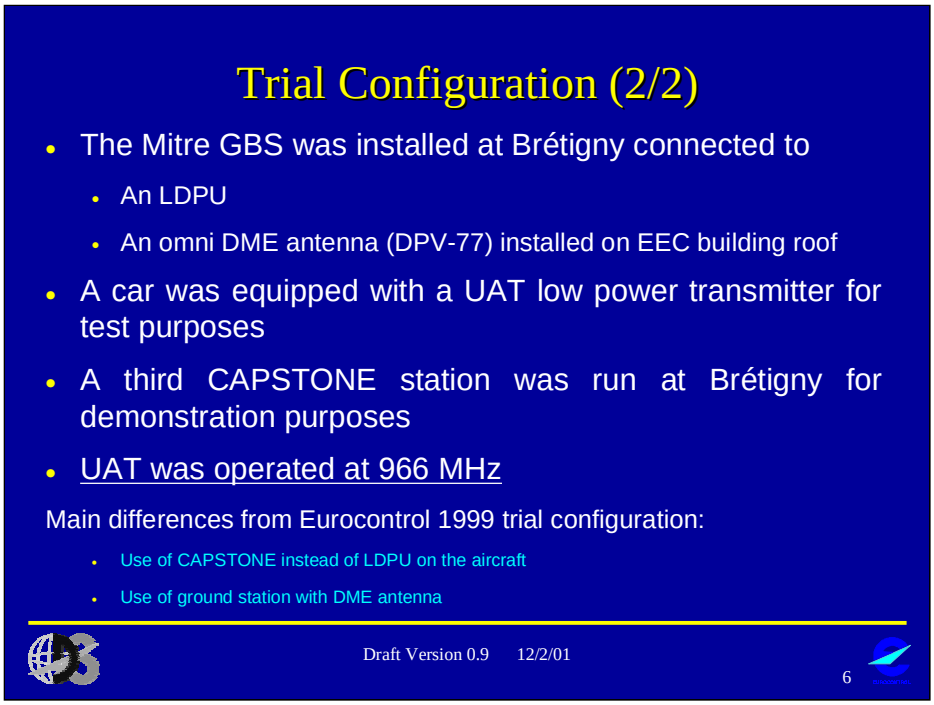

The UPS-AT LDPU incorporates two 1090 ext. squitter receivers and one UAT transceiver.

This unit had been used also in the 1999 trials. The 1090 reception capability was deactivated in the UAT trial.

In the 1999 trials an avionics blade omni antenna had been used for the ground station.

The car UAT transmitter was supplied by UPS-AT.

The 966 MHz channel was also used in the 1999 trials.

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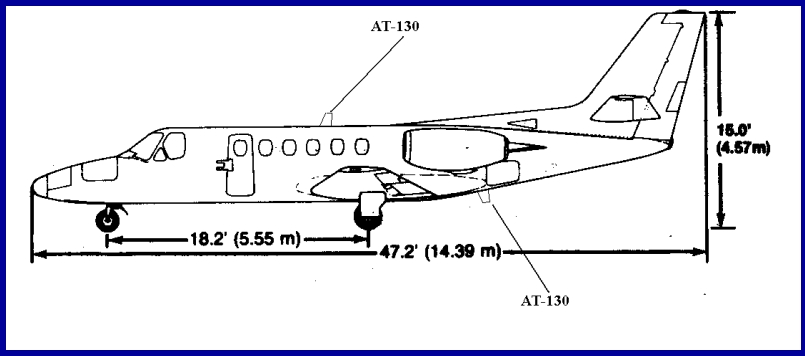
Citation Antenna Placement



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The CAPSTONE kit UAT antennas were used.

Citation Top Antenna, View from Port side Aft

Note pedestal arrangement

The antennas were installed on existing pedestals.

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Citation Belly Antenna

The bottom antenna was off the centerline of the airframe

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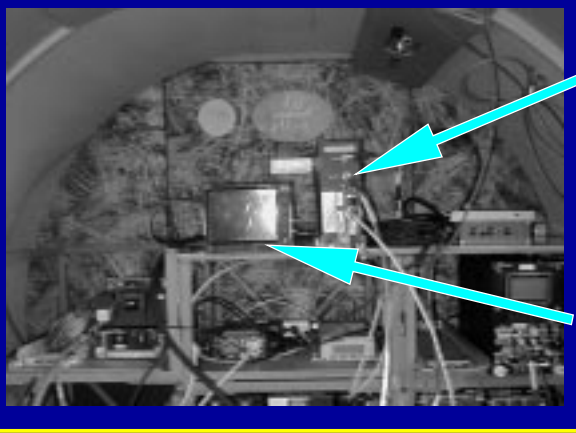
Citation Capstone Equipment Installation



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The CAPTONE equipment was installed on the back of the passenger cabin

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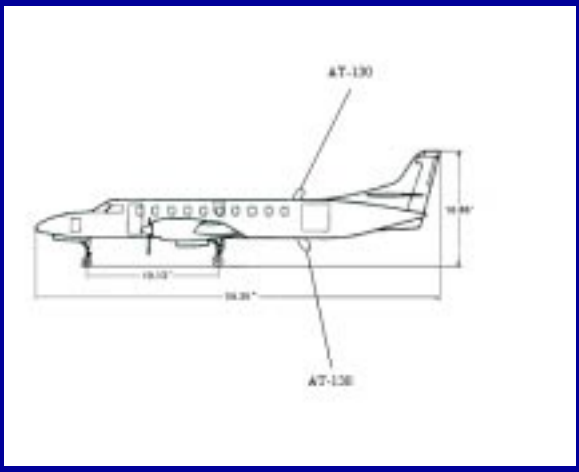
Metro Antenna Placement



The CAPSTONE kit UAT antennas were used.

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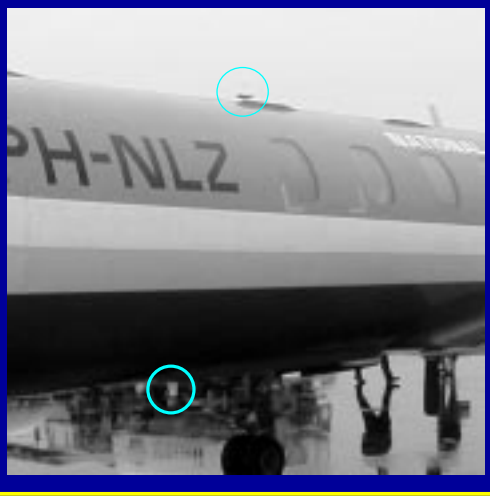
Metro UAT Antennas Closer View



Both antennas were on the centerline of the airframe

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Metro UAT Installation

The UAT radio was installed in the passenger cabin

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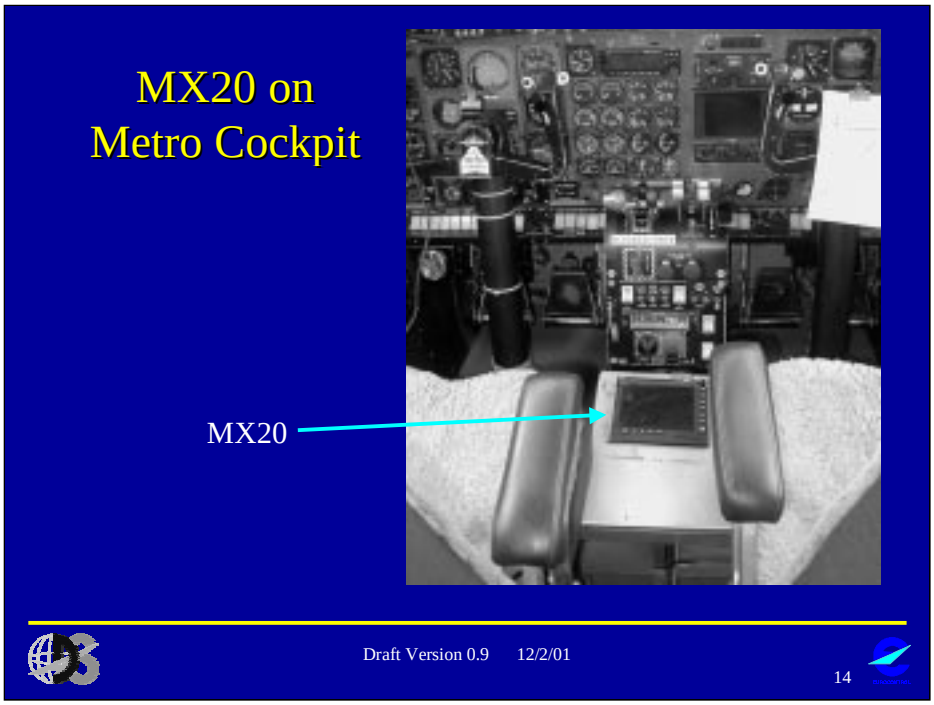

The MX20 was installed on the cockpit.

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Ground Antenna at EEC

Antenna Products Corporation DPV-77

Cable loss to LDPU ~ 2 dB

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The DPV-77 is a DME type omni antenna with a max. gain of ~8 dB and a cone of silence ~75 deg. It was placed on the EEC building roof and had unobstructed view of the Brétigny airfield which is next to the EEC building.

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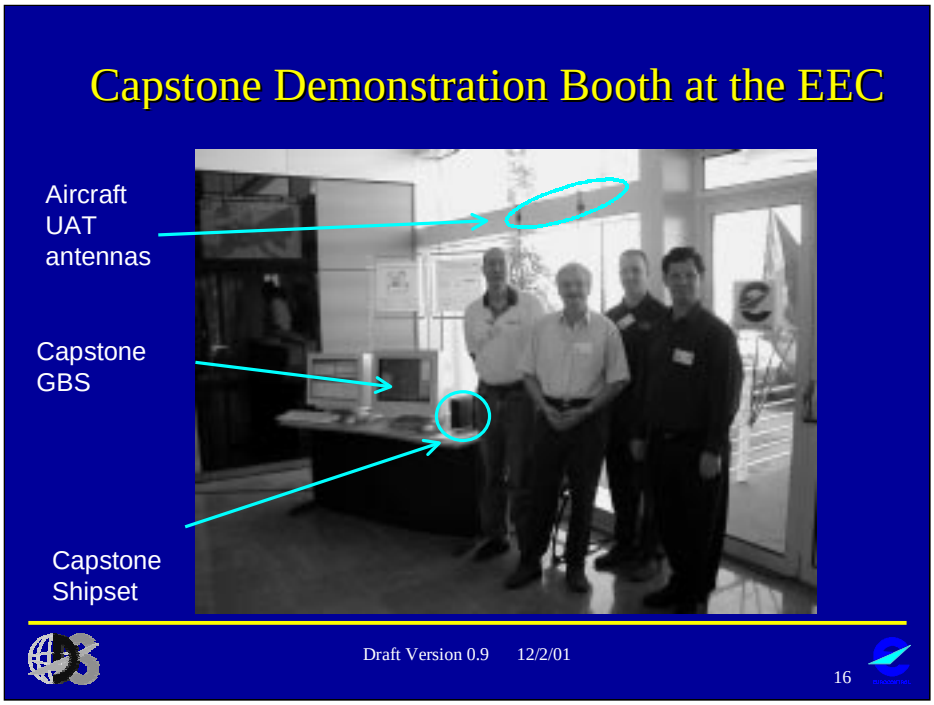

Coinciding with the trials, the EEC organised a three day ATC symposium to inaugurate the the restored EEC building.

The UAT trial flights served as a demonstration of UAT capabilities. For this purpose the ground station plus a CAPSTONE avionics kit were installed at the entrance of the EEC building, from where the adjacent airfield could also be seen.

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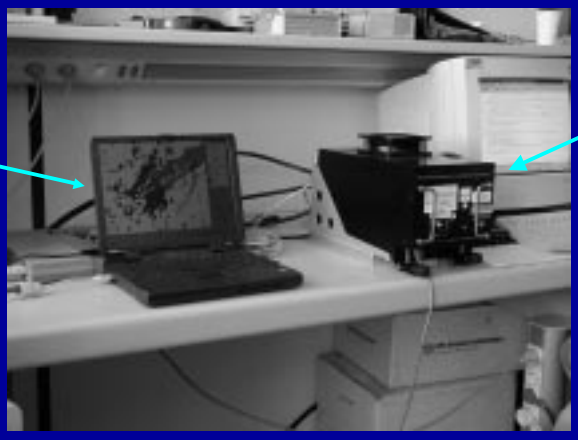
EEC Ground Station



The ground station uplink capability was used to demonstrate the display of weather on the cockpit display.

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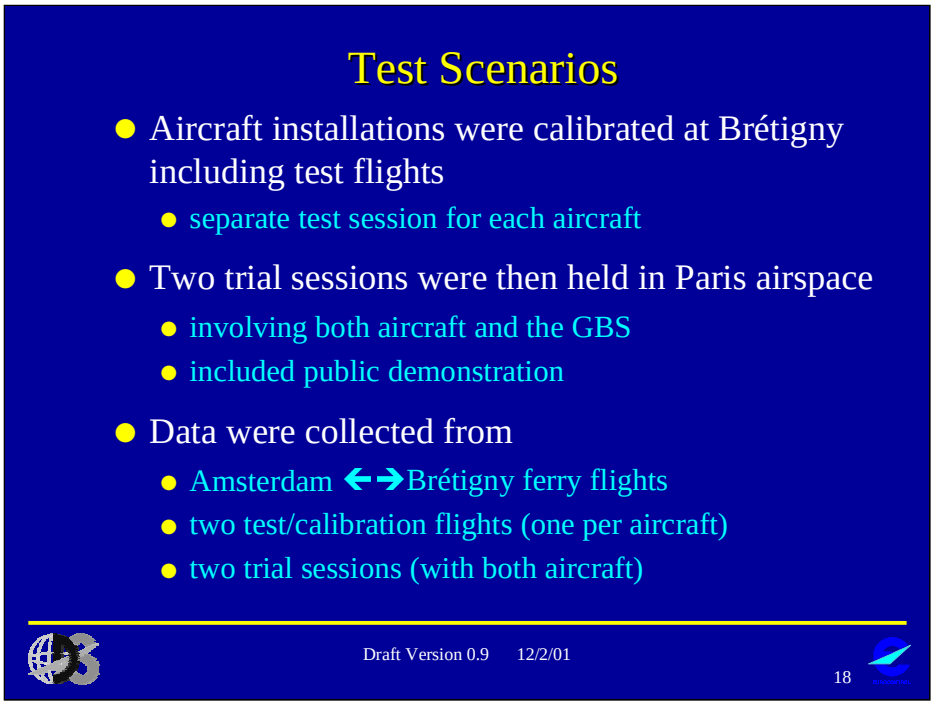

Calibrations included measurements of

- cable losses and antenna VSWR (on site)
- transmitter power and receiver sensitivity (in the lab),
- verification of correct connectivity
- verification of correct radio equipment and data logger operation

All test flights took off from the Brétigny aerodrome.

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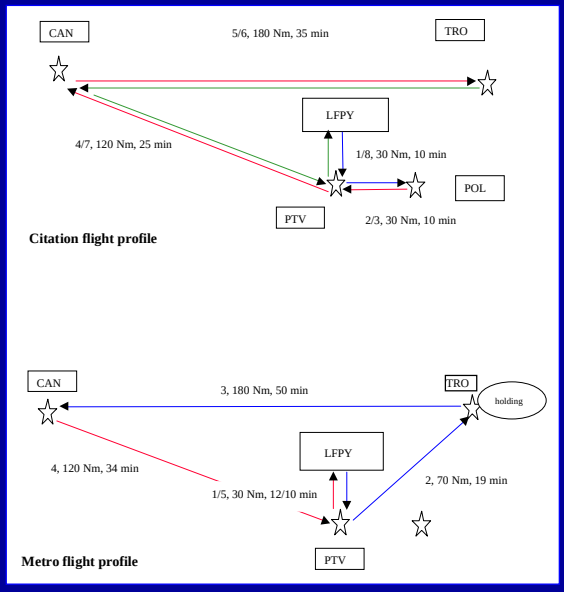
Trial Flight Profiles

- Both a/c started from LFPY
- Initial 90 deg encounter at PTV
- Then racetrack profile CAN-TRO with head to head encounters
- Same profiles on both trial sessions



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The flight profile was defined in collaboration with the aircraft pilots and the military ATC controllers of the Centre d' Essais en Vol, Brétigny and Orly. The latter were responsible for controlling the flights.

Due to the congestion of the airspace around Paris (two major TMAs), the flights had to satisfy numerous constraints.

The Citation was the faster of the two aircraft and always took-off first from Brétigny (LFPY), direction Pithiviers (PTV) and then Polly. When the Citation arrived at Polly (POL), the Metro took-off from LFPY, direction PTV, while the Citation also returned to PTV (for a 90 deg encounter). Then the Citation flew to Caen (CAN) while the Metroliner flew to Troyes (TRO). The Metro waited for the Citation to arrive at CAN and then both aircraft flew along the CAN-TRO line for a head to head encounter, finally returning to Brétigny.

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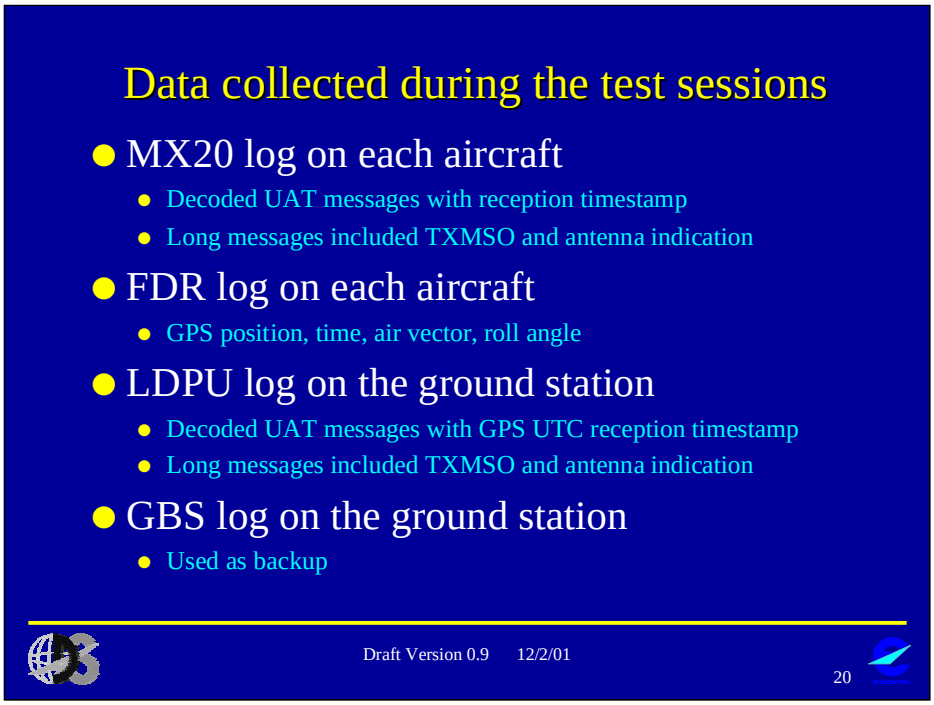

The LDPU includes an inbuilt logging mechanism.

The MX20 log was collected on a portable PC using UPS-AT supplied software.

Both NLR aircraft carry Flight Data Recorders connected to GPS receivers (independent of the UAT ones). Their recording frequency is 10 Hz.

The Mitre GBS has its own logging capability and logs the same types of information as the LDPU. The GBS log was used in the analysis in one case where the LDPU log failed (28/9).

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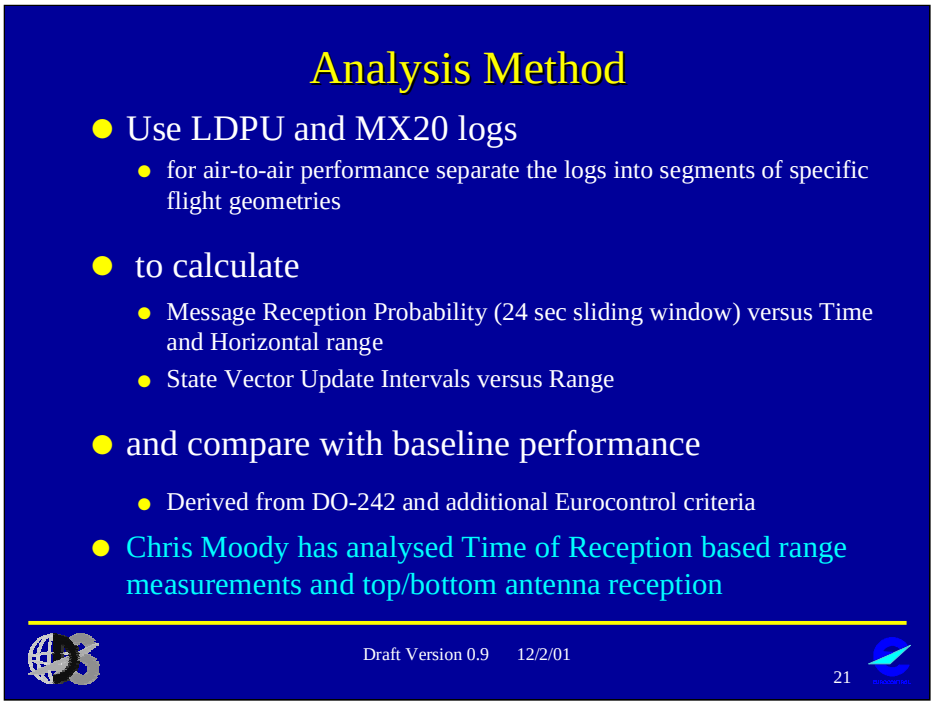

The UAT radios transmit one message per second. Message reception probability is calculated over a period of 24 seconds (assumed to correspond to the track drop interval).

The 24 -sec time window slides per second.

The corresponding distance is calculated for the median position in the time window.

Distance is calculated as great circle distance. No slant correction is applied.

Each UAT message received is assumed to correspond to a state vector update. Then, the difference between the reception timestamps of successive messages indicates the SV update interval.

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Performance Baseline (1/2)
Air-to-Ground

State Vector Updates

Distance Range nmi	Update Period sec	Confi-dence %	Minimum Rec. Prob. %
0-5	1.5	95	86.4
5-10	3	95	63.2
10-60	5	99	60.2
60-150	10	99	36.9

- Corresponds to requirements stated in the draft Eurocontrol ATS enhanced surveillance standard
- Minimum reception probability values are derived from a DO-242 formula linking update intervals to reception probabilities
- **CAPSTONE equipment is considered as class A1.**

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The draft Eurocontrol surveillance standard refers to the update intervals required for TMA and en-route ATS surveillance, Coverage requirements refer to a single ground station.

Requirements at < 10 nmi refer to parallel approaches with runway separation > 2500ft.

The DO-242 formula links report update period (T) and update probability (P) through the equatio $(1-P)^{TC/T} <= 1-P_c$ where TC is the required confidence and TC the corresponding update interval value.

It should be noted that long range applications apply to class A2/A3 equipment

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Performance Baseline (2/2)
Air-to-Air
State Vector Updates

Distance Range nmi	Update Period sec	Confidence %	Minimum Rec. Prob. %
0-3	3	95	63.2
	6	99	53.6
3-10	5	95	45.1
	10	99	36.9
10-20	7	95	34.8
	14	99	28.0
20-40	12	95	22.1
	24	99	17.5
40-90	12	95	22.1
	24	99	17.5
90-150	12	95	22.1
	24	99	17.5

- Corresponds to Table 3.3-3 of DO-242 extended to 150 nmi
- Minimum reception probability values are derived from the DO-242 formula
- **CAPSTONE is considered as class A1 equipment. Requirements above 20 nmi apply to classes A2/A3**

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DO-243 specifies requirements up to 90 nmi (120 desirable) for flight path deconfliction.

Eurocontrol has requested an extension to 150 nmi for autonomous operations.

The range values apply only in the forward quadrant in the case of flight path deconfliction (DO-242) and autonomous operations (Eurocontrol).

The DO-242 formula is stated in the previous slide.

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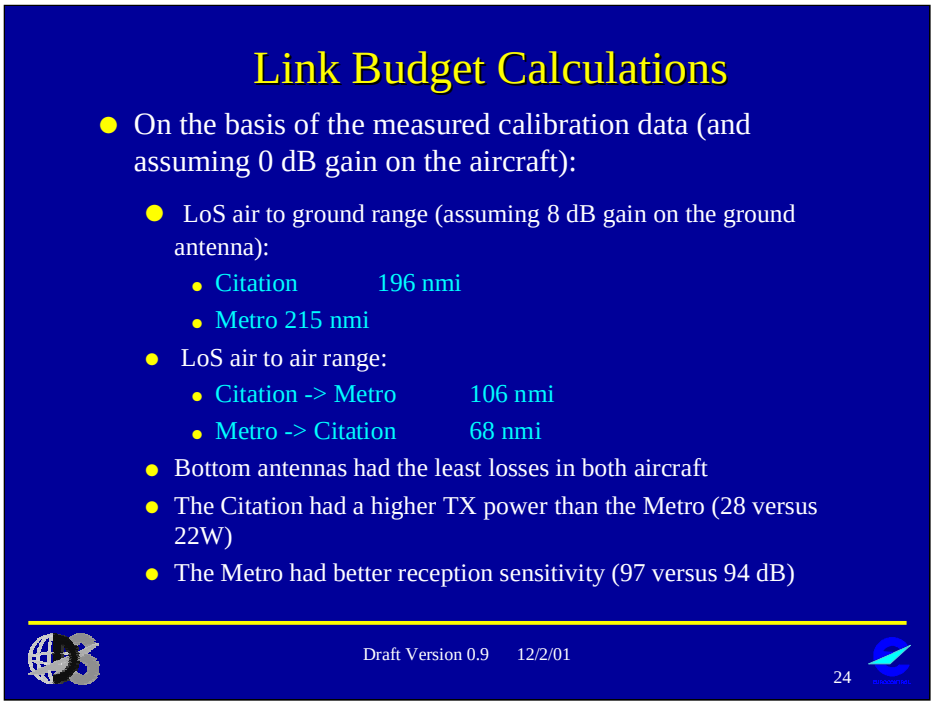

The calculations took into account the cable losses measured in the calibration tests as well as the measured in the lab transmitter powers and sensitivity thresholds (90% reception probability).

The reported TX power values are at the output of the transmitter.

Similarly the reported sensitivity values are at the input of the receiver.

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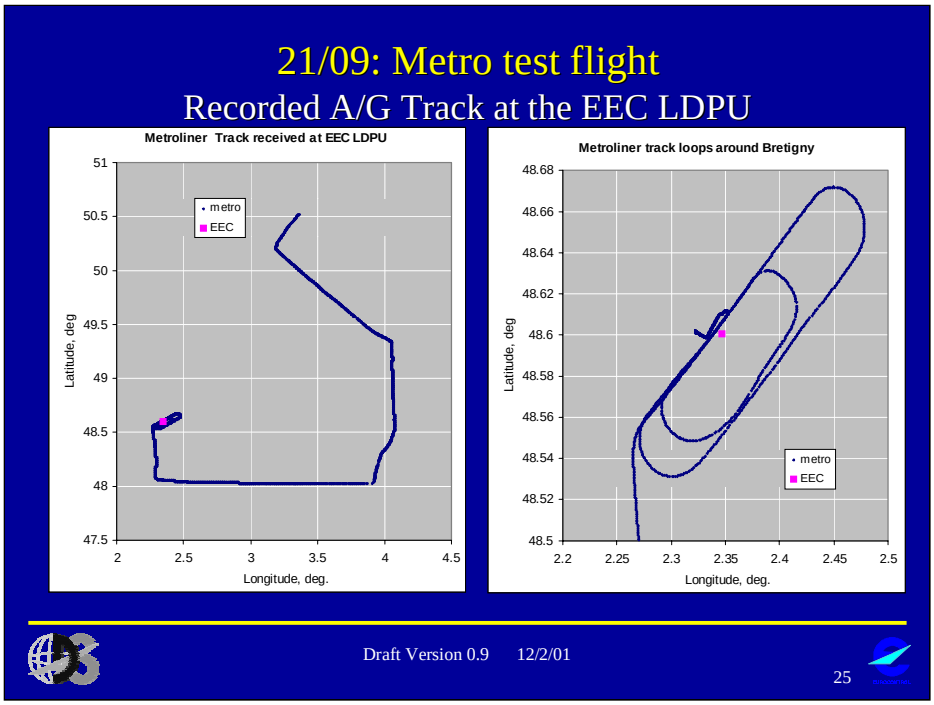
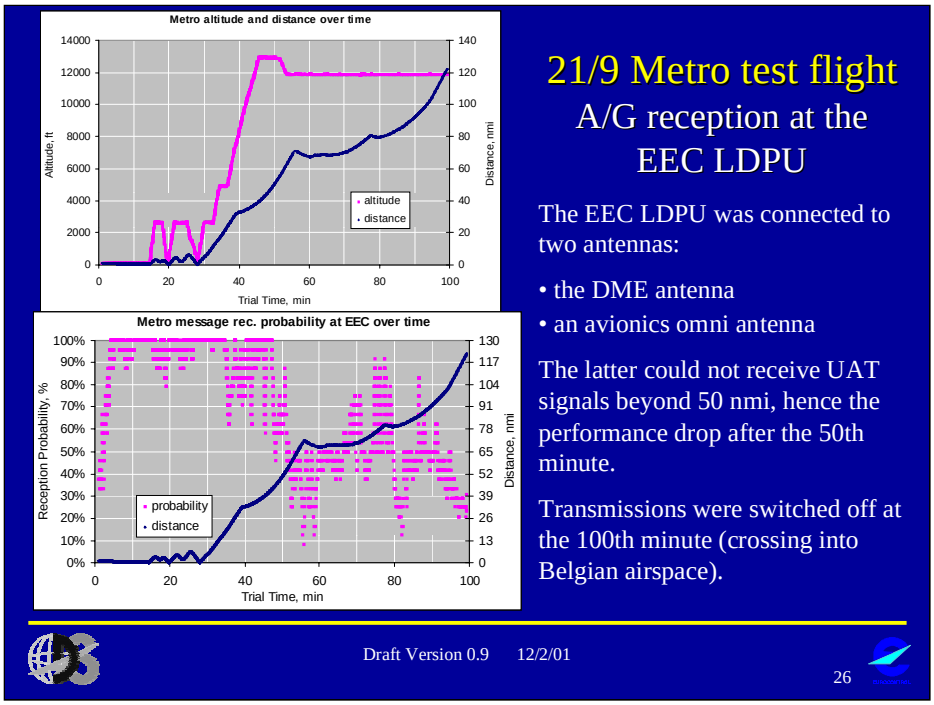


The Metro took off from Brétigny, flew a number of loops around the EEC (see figure on the right) and then returned to Amsterdam.

A dot has been plotted for each Metro position recorded in the EEC LDPU log.



A dot has been plotted for each Metro position recorded in the LDPU log.

Distance has been calculated as great circle distance over a spherical earth. No slant correction was applied.

Reception probability was calculated over a 24 sec sliding time window. The window was moved with each record in the LDPU log.

The second antenna was used to counter the cone of silence of the DME antenna. However the LDPU contains a single receiver and listens alternatively to the one or the other.

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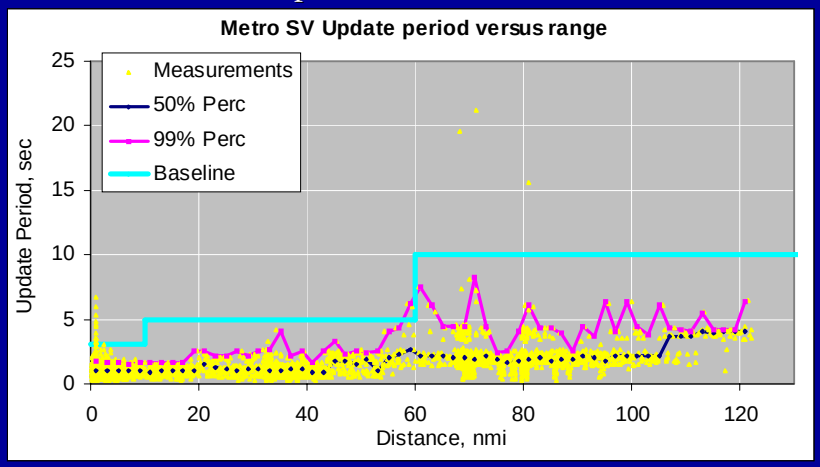
21/9 Metro test flight

A/G reception at the EEC LDPU



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Update interval values are calculated from the GPS reception timestamps of the LDPU log for successive messages. A dot is plotted for each measurement.

The Baseline indicates the maximum required values presented previously.

The xth percentile containment values are calculated over 2 nmi wide distance bins. Distance was calculated as explained in the previous slide.

The graph shows that despite the losses caused by the non DME antenna used, the received update intervals stayed below the required maxima throughout the recorded flight.

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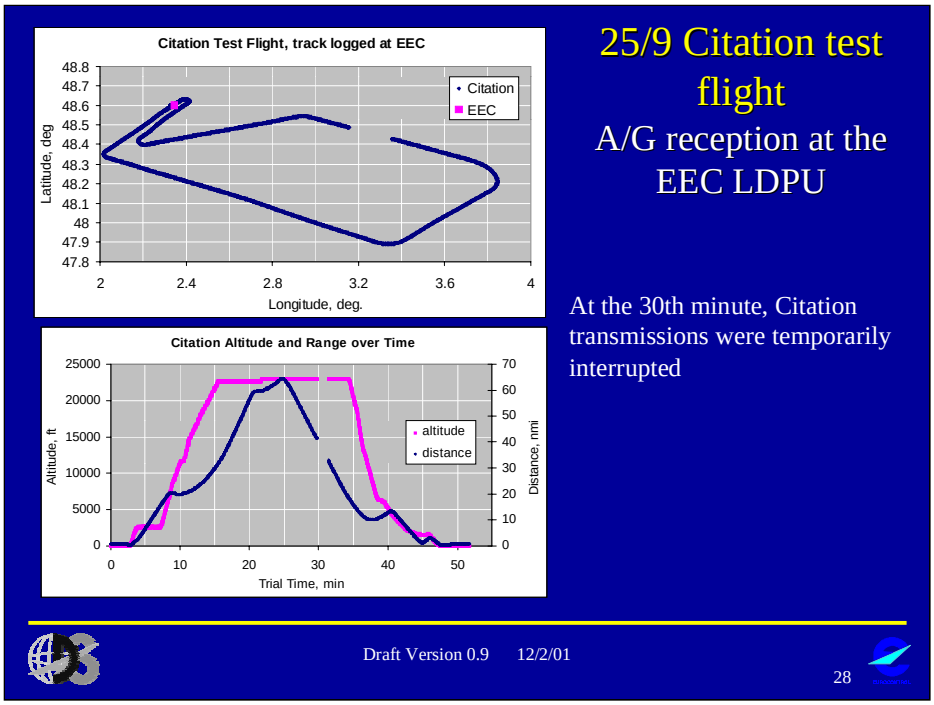

The Citation took off from Brétigny and flew a loop towards the SE returning to Brétigny. One dot is plotted for each record in the LDPU log.

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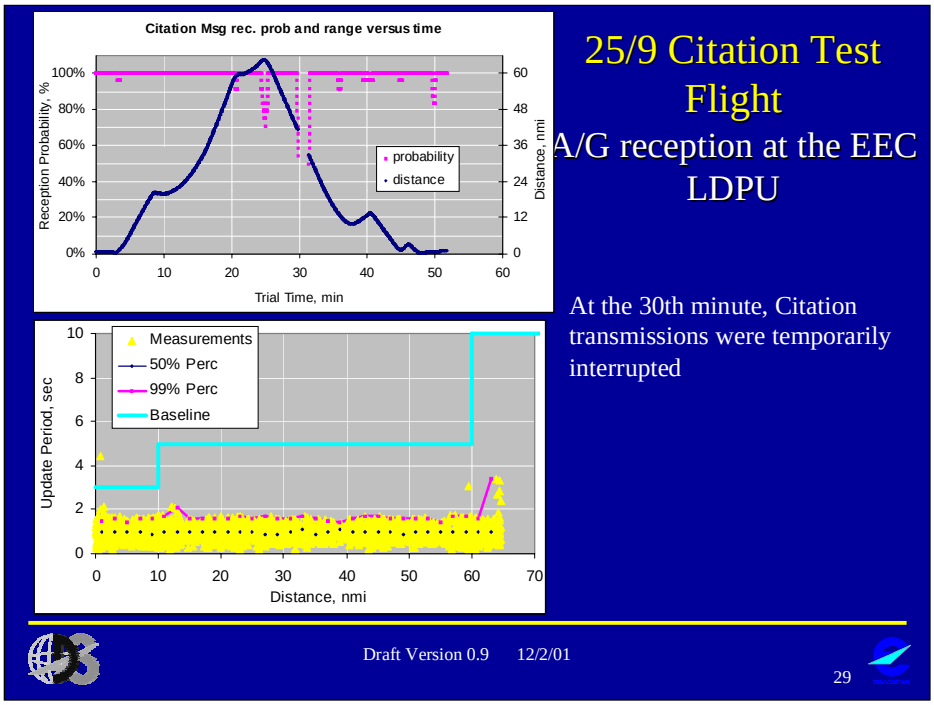

The above figures were produced using the same techniques as in the case of the slides for the 21/9.

The above figures show that performance stayed comfortably within the requirements throughout the 60 nmi range.

The xth percentile containment values are calculated over 2 nmi wide bins.

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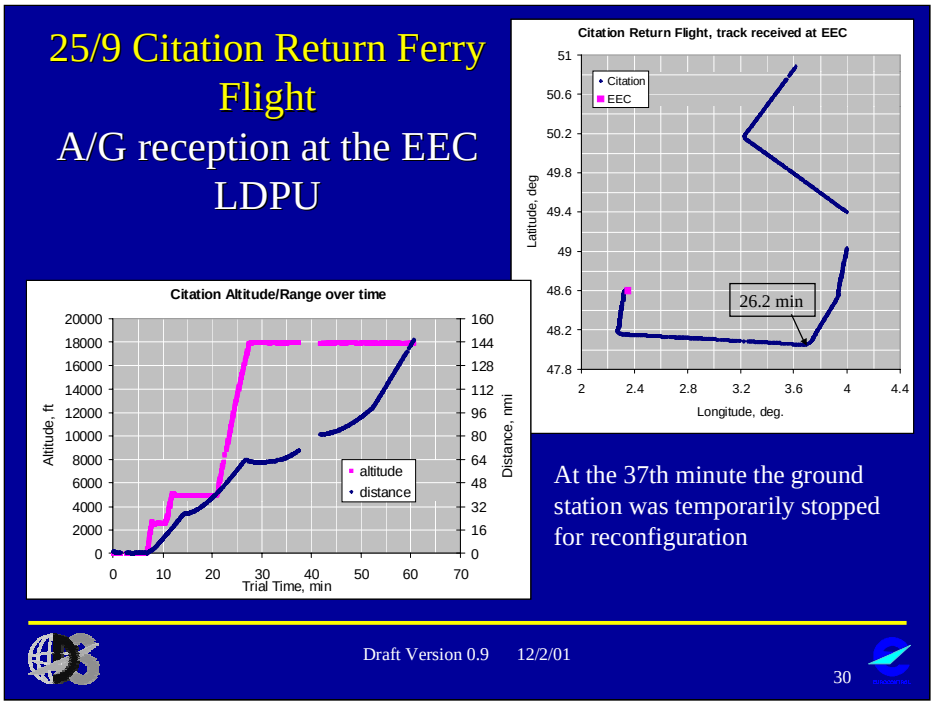

One dot is plotted for each record in the LDPU log.

After the test flight described in the previous two slide, the Citation returned to Amsterdam.

Citation transmissions were stopped at the 60th minute while it crossed into Amsterdam TMA.

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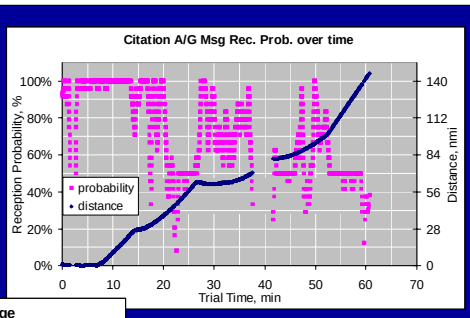
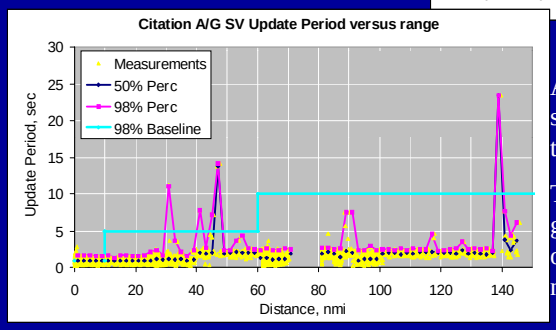
25/9 Citation Return Ferry Flight

A/G reception at the EEC LDPU





At the 37th minute the ground station was reconfigured hence the reception gap.

The use of two antennas on the ground station provoked the loss of performance beyond the 50th nmi

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The above graphs were calculated using the same techniques as those described for the slides of the 21/9.

The EEC ground station LDPU was connected to both the DME and the avionics omni antenna. The latter started to lose messages beyond 50 nmi.

The update interval graph shows that the TMA requirements were violated in the period 20 to 25 min, e.g. before the north turn of the Citation. The en-route requirements were met up to 140 nmi despite the potential antenna configuration problem.

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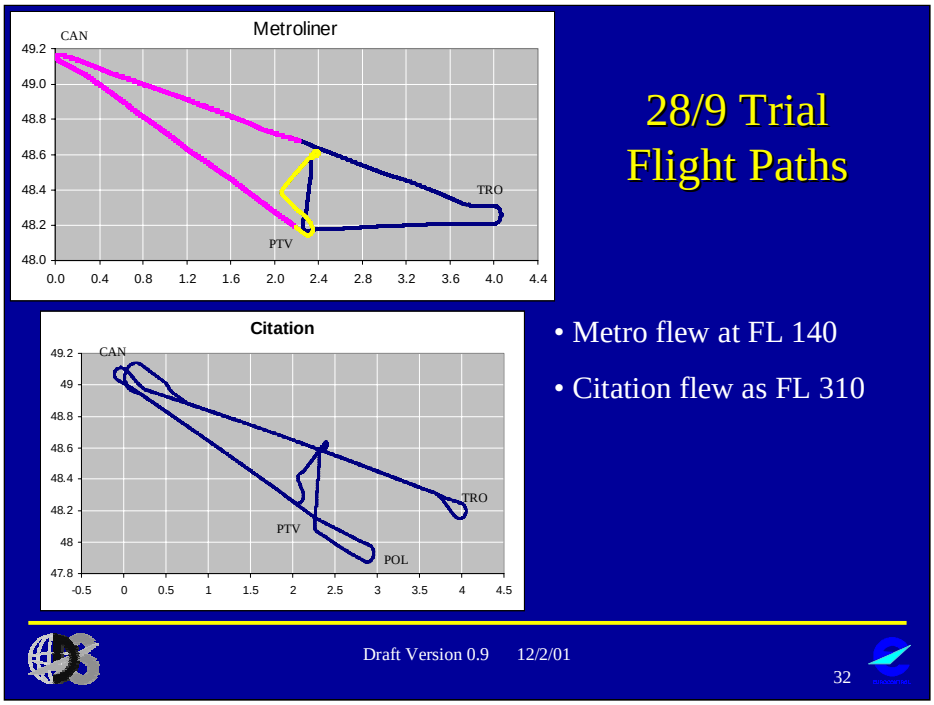

Both tracks are dot per record plots of the flight data recordings collected onboard each aircraft.

There was one recording interruption on the Metro which caused the visible gap towards TRO.

Due to a pressurization problem in the Metro, it was not possible for this aircraft to fly above FL150. Air traffic constraints required both aircraft to fly above FL300. In the end it was decided to fly the Citation flew at FL310 and the Metro at FL140.

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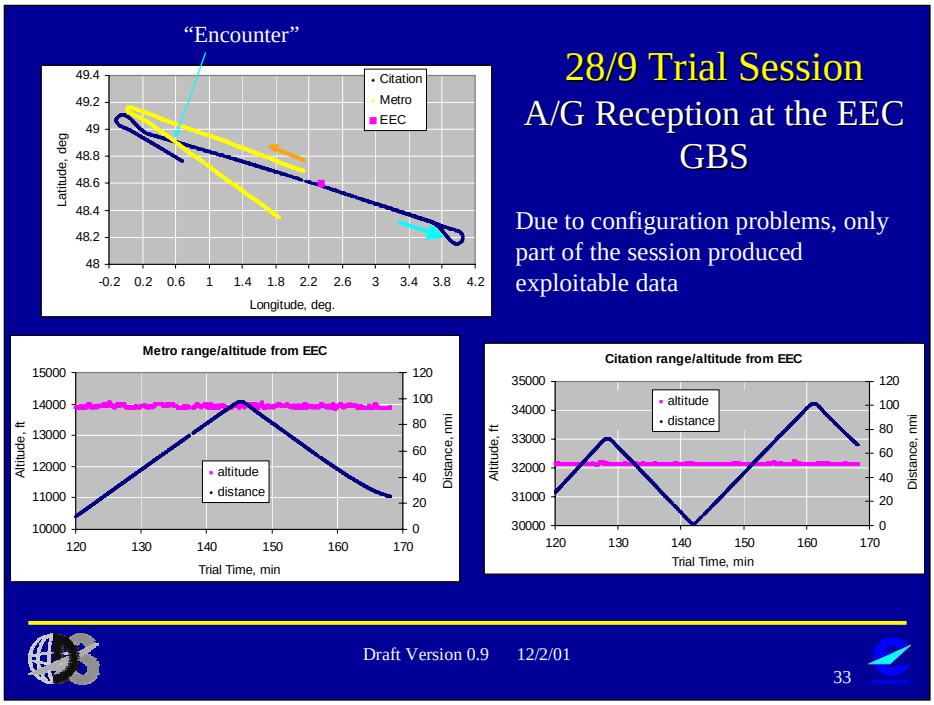

The above graphs were calculated using the same techniques as those described for the slides of the 21/9.

Both aircraft applied the flight profiles agreed. Unfortunately there were problems with the configuration of the equipment on the aircraft. Consequently parts of the flight session did not produce exploitable data.

In this segment of the flight session the two aircraft were initially flying tail to tail, then first the Citation and then the Metro turned 180 deg, and flew towards each other for a head to head encounter, albeit at widely varying flight altitudes.

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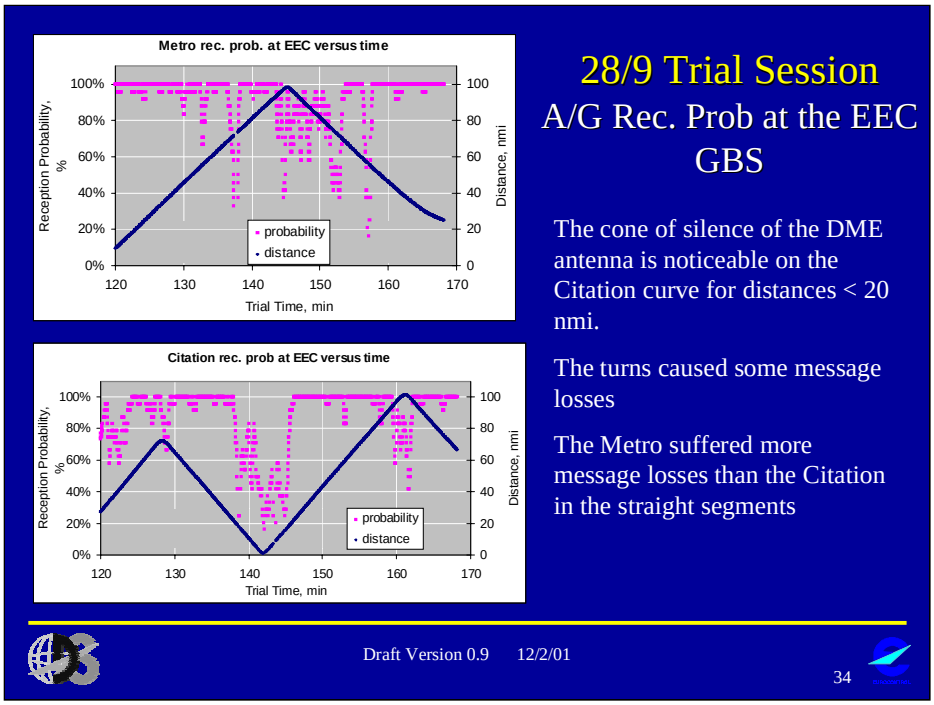

The above graphs were calculated using the same techniques as those described for the slides of the 21/9.

The EEC ground station was connected to a single antenna (the DME one).

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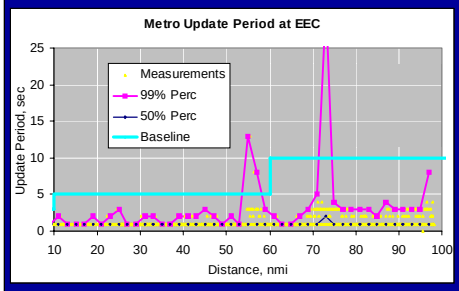
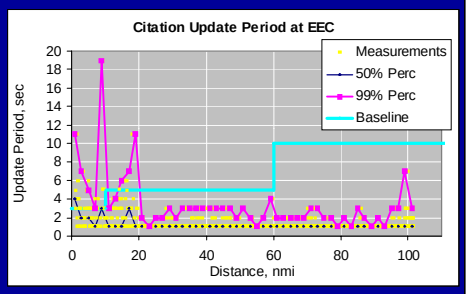
28/9 Trial Session

A/G Update Period versus range at the EEC LDPU





Citation performance at distances < 20 nmi is affected by the DME antenna cone of silence

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The above graphs were calculated using the same techniques as those described for the slides of the 21/9.

Apart from the cone of silence effects, the Citation performance stayed within the requirements.

The Metro suffered two short periods of poor performance, but apart from these it also satisfied the requirements.

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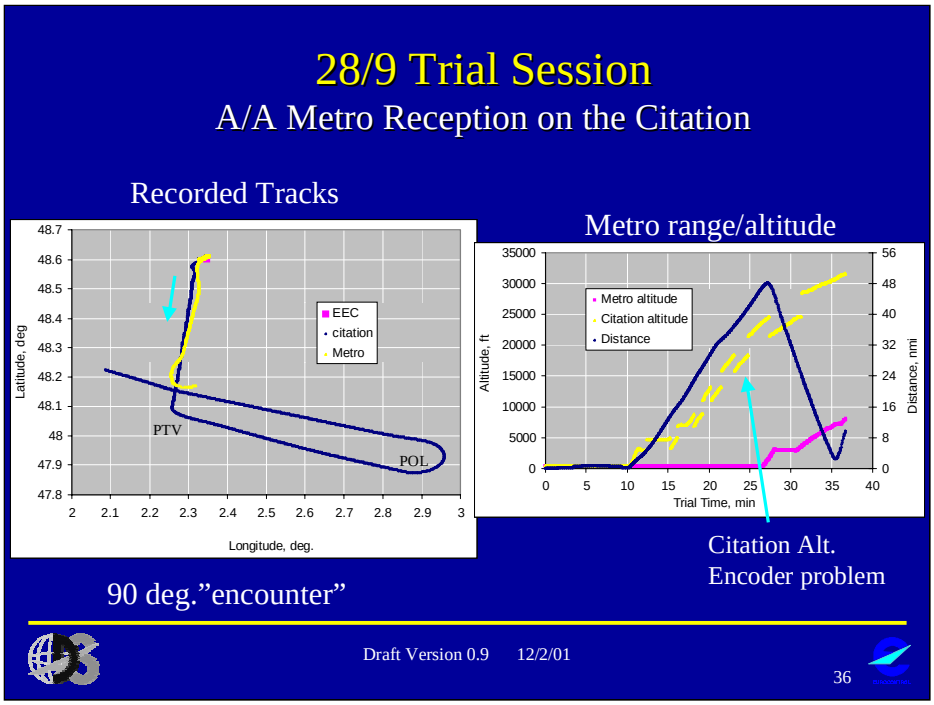

One dot is plotted for each Metro position record in the Citation MX20 log. The latter records Metro position for each Metro message received and decoded successfully.

A/A distance was calculated per Metro record in the Citation MX20 log using the lat/long coordinates contained therein. The MX20 log contains also own positions (from own emissions). The receiver and target coordinates were correlated by using the GPS reception timestamps recorded by MX20. Range was calculated as great circle distance over a spherical earth. No slant correction was applied.

This segment is from the beginning of the session. The Citation took off first from Brétigny and flew to Pithiviers (PTV) and then Polly (POL). Then, the Metro took off from Brétigny and both aircraft flew towards PTV for a 90 degree encounter, albeit with widely varying flight altitudes. Both aircraft were climbing during the encounter.

On this session, the altitude encoder on the Citation started malfunctioning and thus Citation altitude readings were somewhat distorted.

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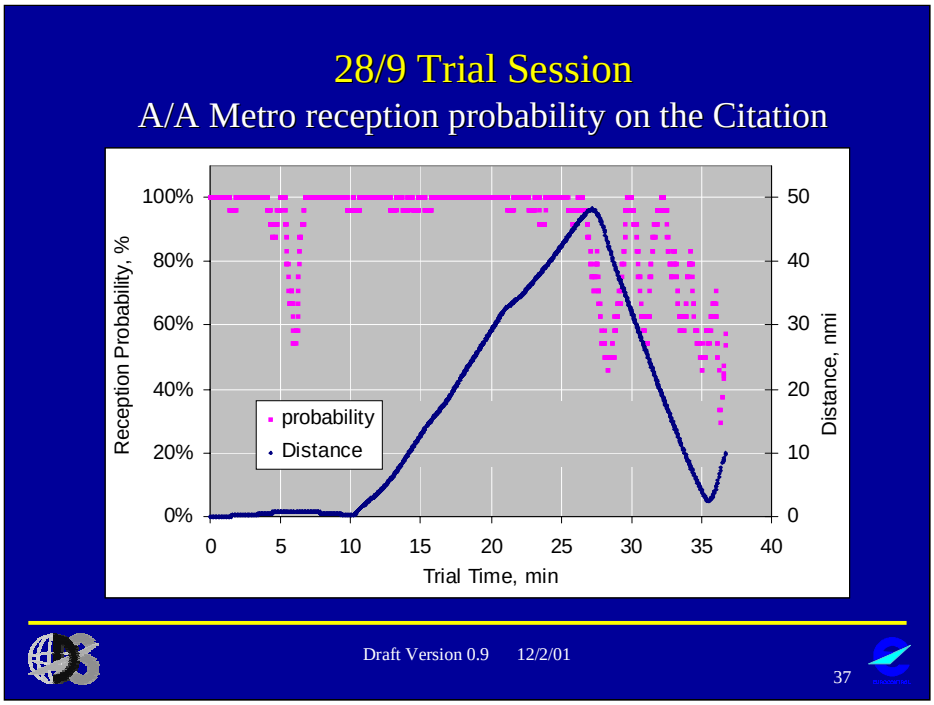

Target reception probability was calculated over a 24 sec sliding time window. The corresponding distance is that of the median position in the time window.

The Citation took of at the 10th minute. The Metro took off around the 25th minute.

The encounter occurred at the 35th minute.

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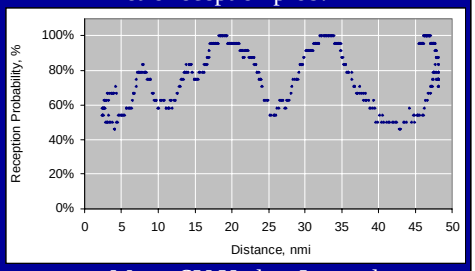
28/9 Trial Session

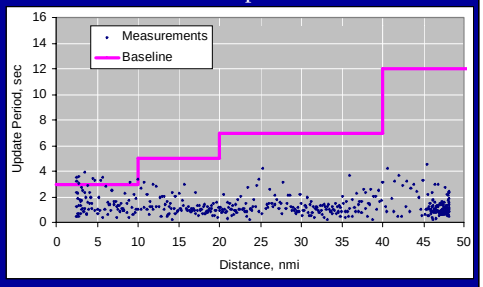
A/A Metro reception on the Citation

90 deg. “encounter” segment

Metro reception prob.



Metro SV Update Intervals



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Target state vector update intervals were calculated from the reception timestamps of successive target positions in the MX20 log. On dot is plotted for each update interval measured.

The Baseline indicates the maximum acceptable interval values which were defined in a previous slide, based on DO-242.

This flight segment starts when the Metroliner takes off and lasts until the two aircraft cross each other’s path over Pithiviers.

The observed update intervals are largely below the required maxima except at ranges below 10 nmi.

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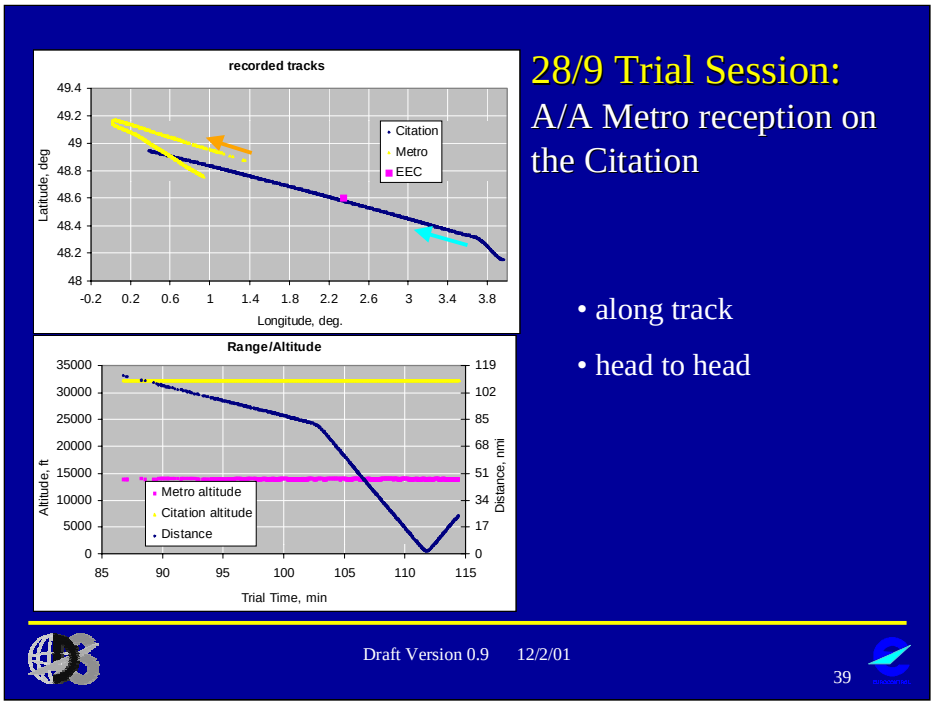

A dot is plotted for each Metro record in the Citation MX20 log. The a/a distance calculation method has been explained in a previous slide.

In these segments the Citation was flying from Troyes to Caen. The Metro was also flying to Caen wher it executed a 180 deg turn and flew towards the Citation. During the encounter the aircraft were vertical separated by about 16000ft.

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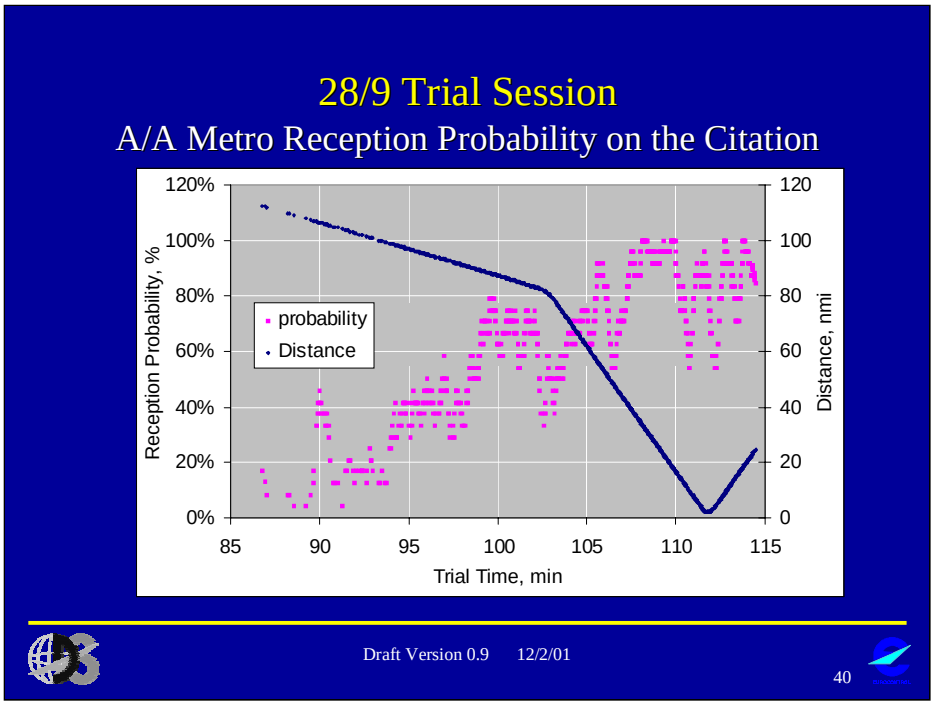

The target reception probability and range calculation methods used have been defined previously.

The Citation flew at a much higher speed than the Metro.

Reception probability increased as the distance between the two aircraft was reduced.

There may have been a bottom transmission blocking effect as the Metro flew underneath the Citation (15000 ft difference).

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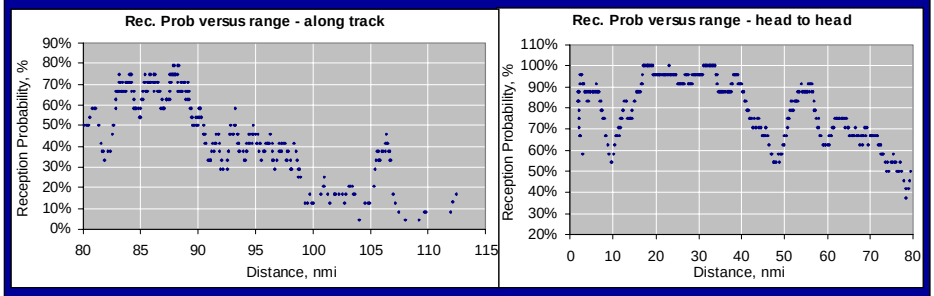
28/9 Trial Session

A/A Metro reception probability on the Citation



Reception performance during the two flight configurations

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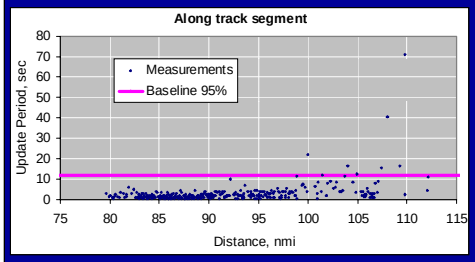
The target reception probability and range calculation methods used have been defined previously.

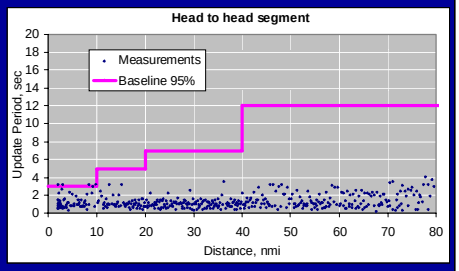
Reception performance increased during the along track phase as range was reduced.

In the had to head phase reception performance rapidly increased to 100% as the aircraft approached each other, although there were two periods where performance was reduced to 50% suggesting that blocking of one of the antennas may have occurred in that geometry.

28/9 Trial Session

A/A Metro SV update intervals on the Citation





Reception performance during the two flight configurations

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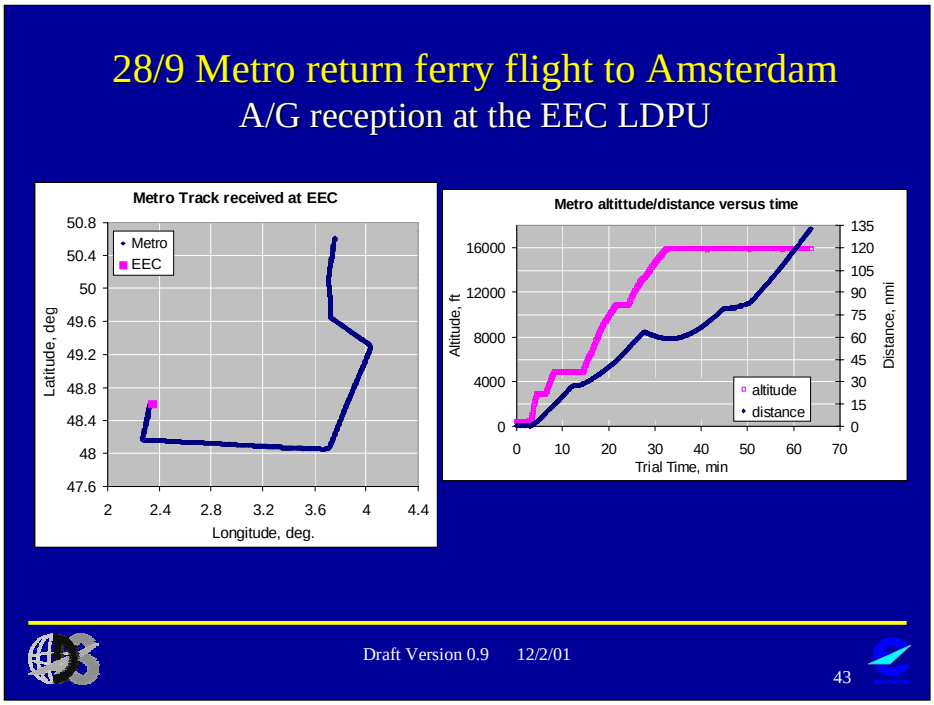
The target update interval and range calculation methods used have been defined previously. The baseline indicates maximum acceptable values defined per DO-242.

In the along track phase, update intervals stayed below the required maximum up to at least 100 nmi, which is more than the projected range from the link budget calculations.

In the head to head phase, update intervals stayed well below the required maxima throughout except for distances below 10 nmi.

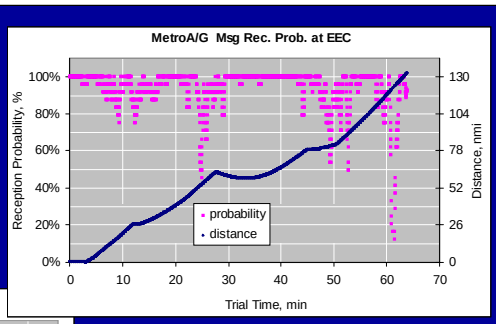


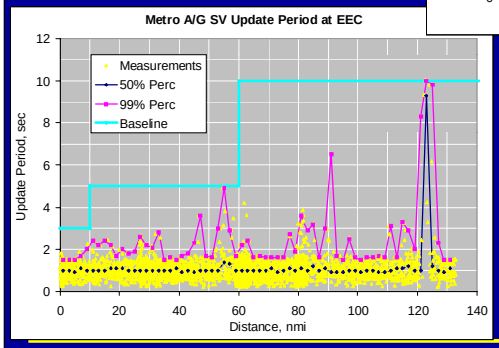
A dot is plotted for each Metro position recorded in the LDPU log. The a/g range calculation method has been explained previously.

Metro transmissions were switched off when the aircraft entered into the Belgian airspace.

28/9 Metro return ferry flight to Amsterdam

A/G reception at the EEC LDPU





This time only the DME antenna was used with the EEC LDPU. Consequently, there was no performance drop beyond 50 nmi, as seen in the test sessions of 21/9 and 25/9

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The target reception probability, state vector update interval and range calculation methods used have been defined previously. The baseline indicates (draft) maximum acceptable values defined by Eurocontrol for TMA and en route ATS surveillance.

The above graphs should be compared with the performance seen in the Metro ferry flight of the 21/9. It can be seen that performance on the 28/9 ferry flight was better, and this is due to the use of a single (DME) antenna. There were some message losses but the received update intervals stayed below the required maxima.

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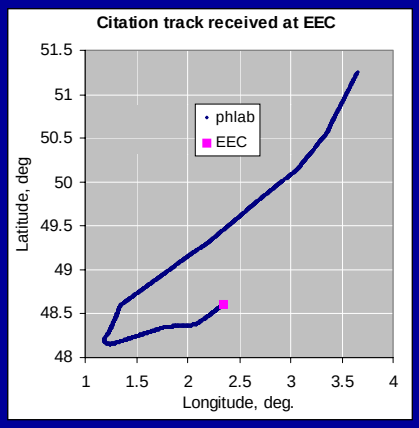
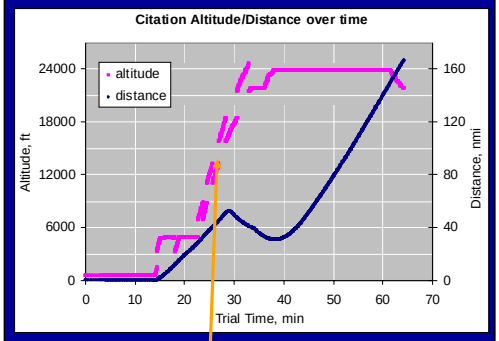
29/9 Citation return ferry flight to Amsterdam

A/G reception at the EEC LDPU





Altitude encoder problem

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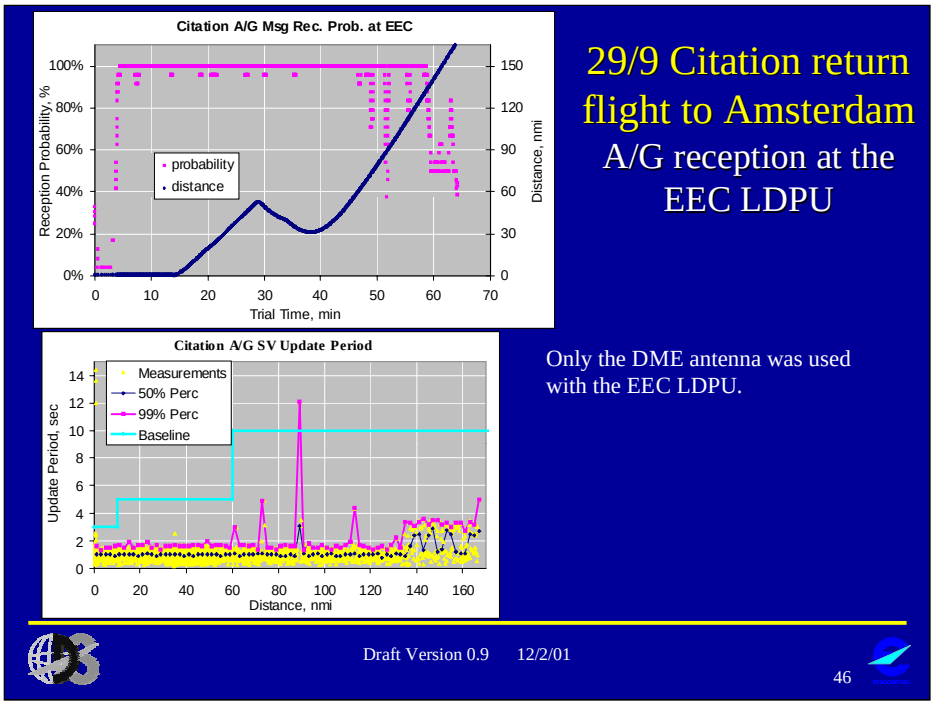
A dot is plotted for each Citation record in the LDPU log. The a/g distance calculation method has been explained previously.

On the 29/9 a demonstration session was held to coincide with the inauguration of the EEC building. After the demonstration, the Citation returned to Amsterdam. The above graphs refer to this return flight.



The same calculation techniques were used as in the case of the 25/9 Citation flight.

The above graphs should be compared with the performance seen in the Citation ferry flight of the 25/9. The difference is that on the 29/9 a single (DME) antenna was used. It can be seen that performance on the 29/9 ferry flight was better. There were some message losses but the received update intervals stayed mostly below the baseline maxima.

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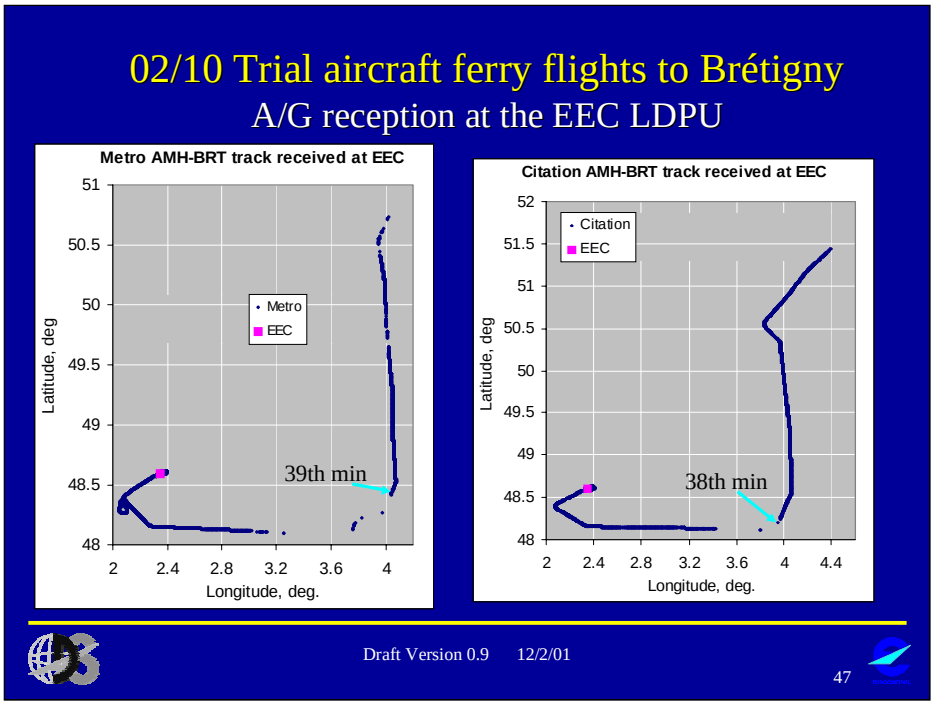

One dot is plotted for each target record in the LDPU log.

The two aircraft flew at the same time.

The Citation track has clearly fewer drops. The Citation UAT radio had higher transmission power (by ~1 dB) while its TX cable losses were lower by 1 dB.

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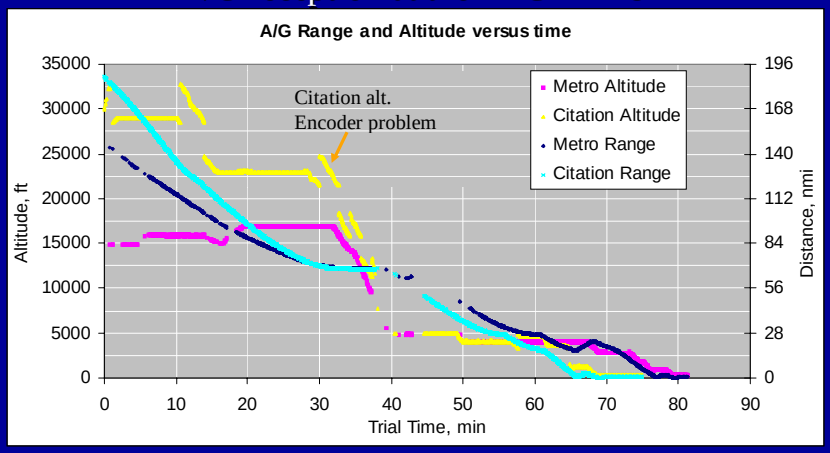
02/10 Trial aircraft ferry flights to Brétigny

A/G reception at the EEC LDPU



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One dot is plotted for each target record in the EEC LDPU log. The a/g distance calculation method has been described previously.

Both targets appeared at about the same time. The Citation was behind and at a higher altitude but it overtook the Metro because of its higher speed.

There is noticeable correlation of losses when both aircraft were at similar positions and altitudes (~39th minute).

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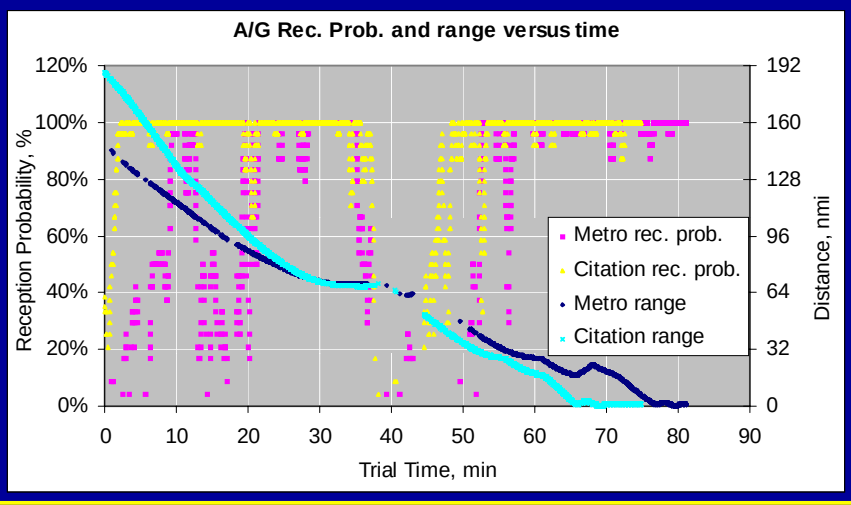
02/10 Trial aircraft ferry flights to Brétigny

A/G reception at the EEC LDPU



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The reception probability has been calculated over a 24 sec sliding time window.

A/g distance has been calculated per recorded target position as great circle distance over spherical earth. No slant correction has been applied.

The poor performance of the Metro is clear, certainly in comparison with previous sessions. The Citation did better except for the period 38-45 min when the tracks of both aircraft were lost.

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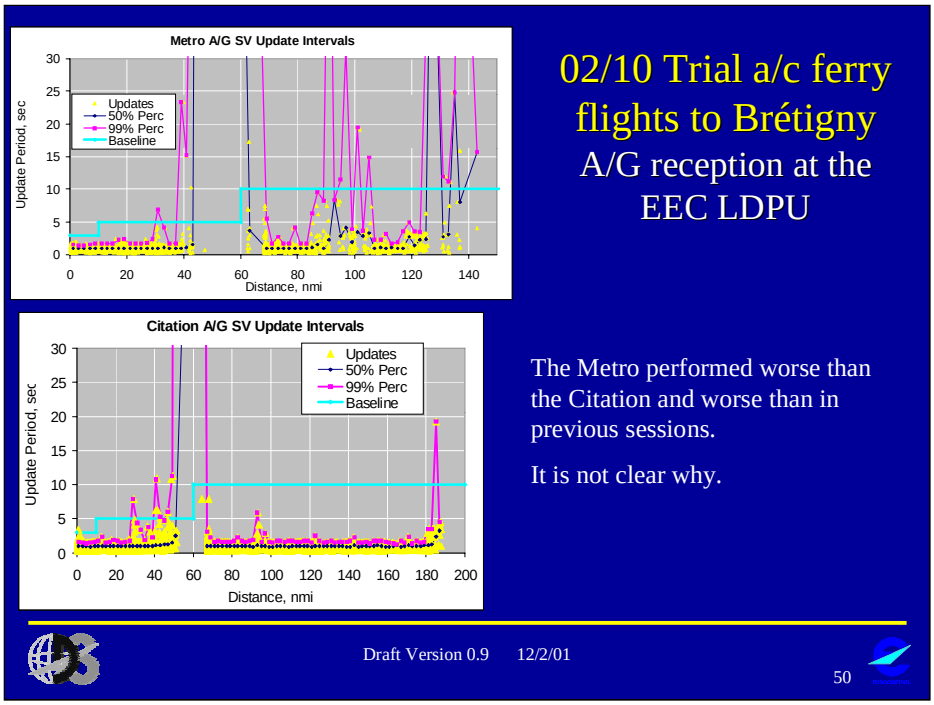

Update intervals were calculated from the reception timestamps of successive target plots in the MX20 log.

The 99th percentile containment values were calculated for 2 nmi wide range bins.

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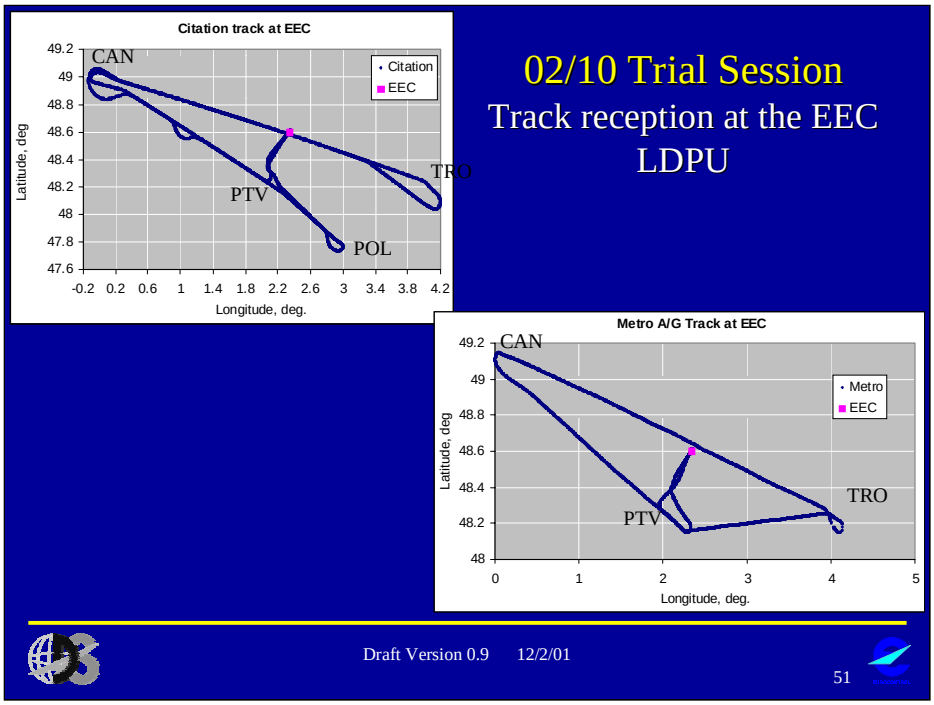

One dot is plotted for each target record in the EEC LDPU.

The same flight profiles were applied as in the session of 28/9.

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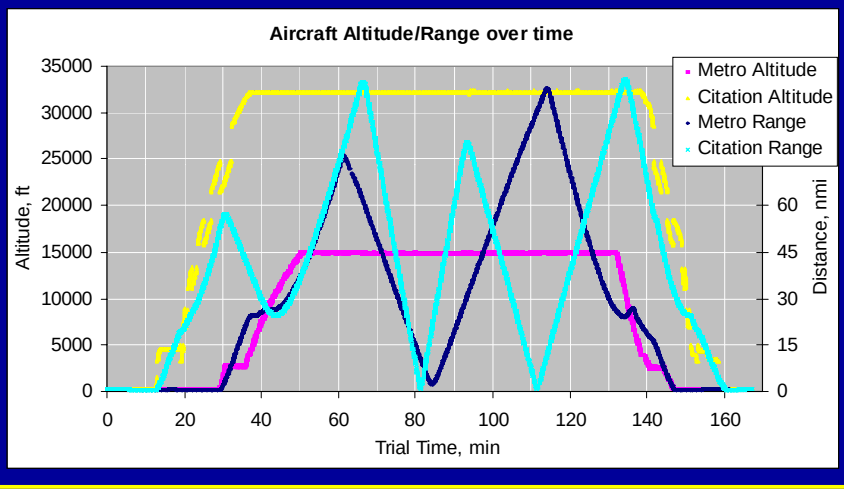
02/10 Trial Session

A/G reception at the EEC LDPU



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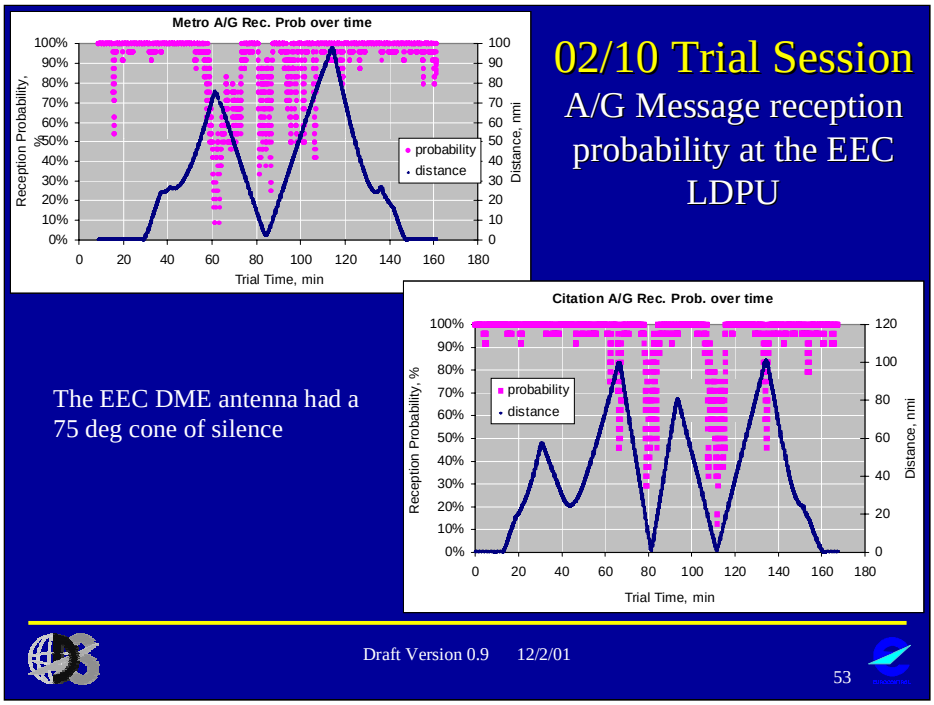
One dot is plotted for each target record in the EEC LDPU log.

The a/g distance calculation method has been explained previously.

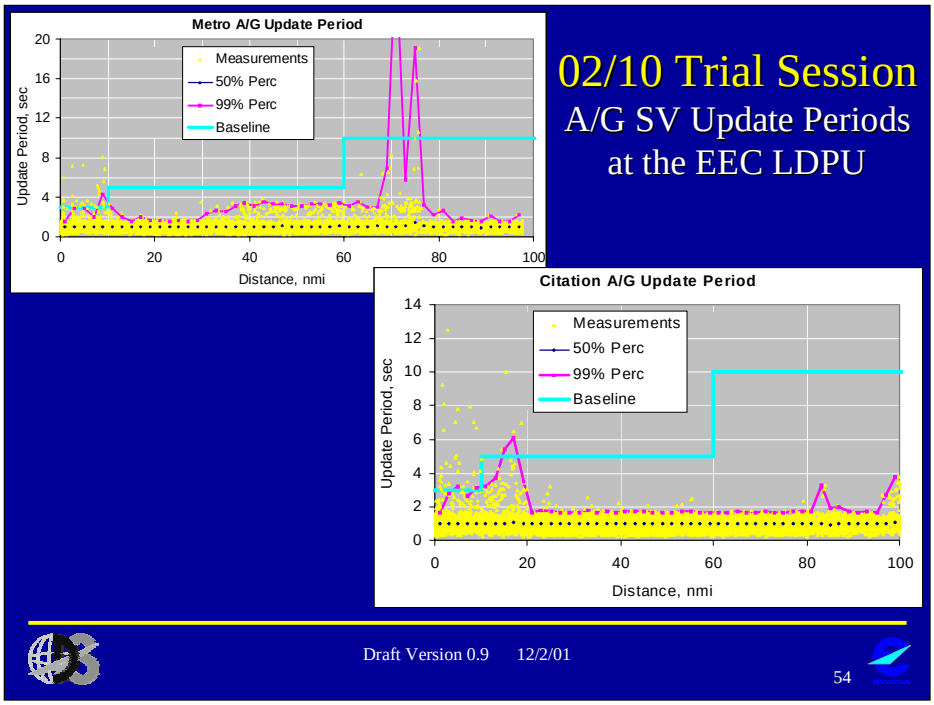
The effect of the faulty Citation altitude encoder is visible.



The calculation methods for reception probabilities and a/g range have been presented previously.

In the case of the Citation message losses occur when the aircraft turns at the two ends of the racetrack and also when it overflies the EEC.

The Metro seemed to lose additional messages, possibly because of the 2 dB difference in radiated power.



The update intervals have been calculated from the GPS reception timestamps in the EEC LDPU log. The 99th percentile containment values have been calculated for 2 nmi wide range bins.

The Citation had better long range performance but seemed to suffer more from the ground antenna cone of silence effects.

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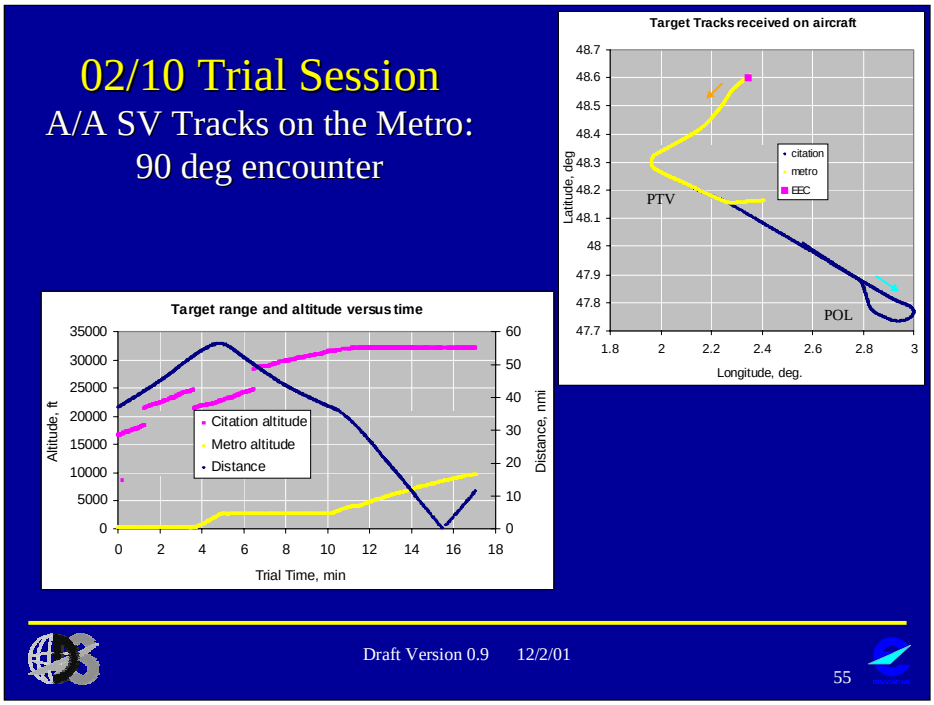

A dot is plotted for every Citation report on the Metro MX20 log. The Metro track is similarly constructed from own reports in the Metro MX20 log. A/A distance has been calculated according to the method explained previously.

This segment is from the beginning of the session. The Citation took off first and flew to PTV then POL, at which point the Metro took off from Brétigny, and then both aircraft flew towards PTV.

The same manoeuvre was analysed previously for the 28/9 session, or reception on the Citation. This time analysis is for Metro reception. The difference in the link budget between the two paths is ~4 dB in favor of Metro reception (bottom to bottom antenna).

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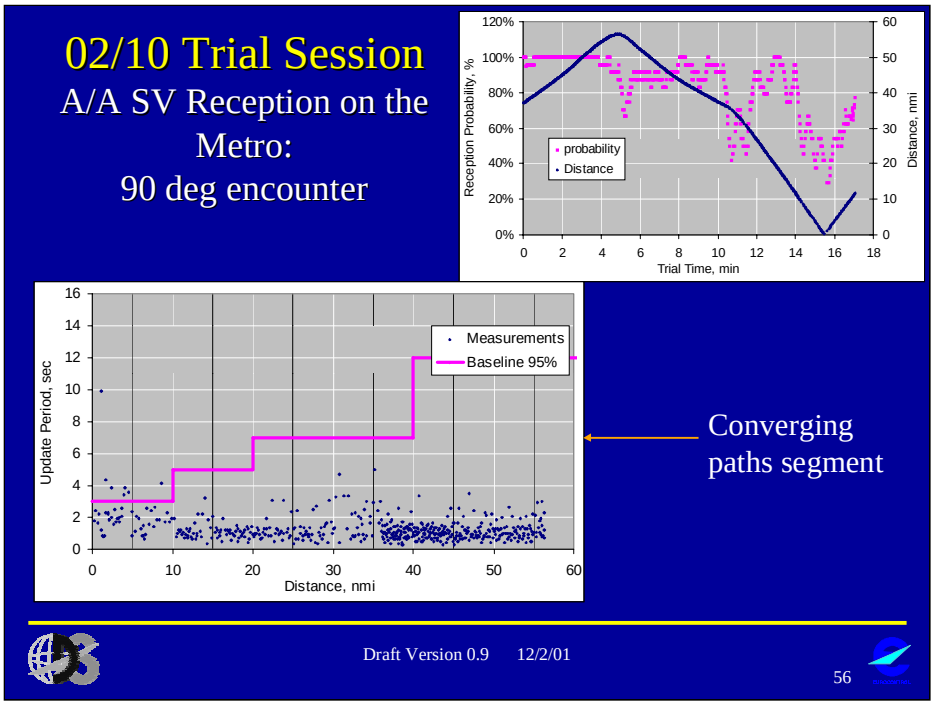

SV update intervals have been calculated from the MX20 reception timestamps.

The baseline is derived from DO-242 requirements.

Reception probability is calculated over a 24 sec sliding window.

There is an evident blocking effect as the Metro passes underneath the Citation, which affects performance in range <= 10 nmi.

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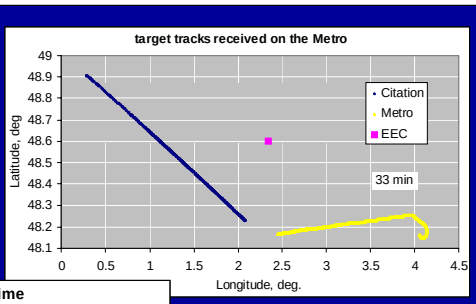
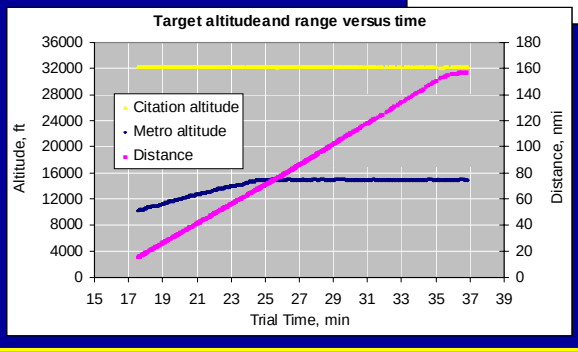
02/10 Trial Session

A/A SV Reception on the Metro: Diverging Paths





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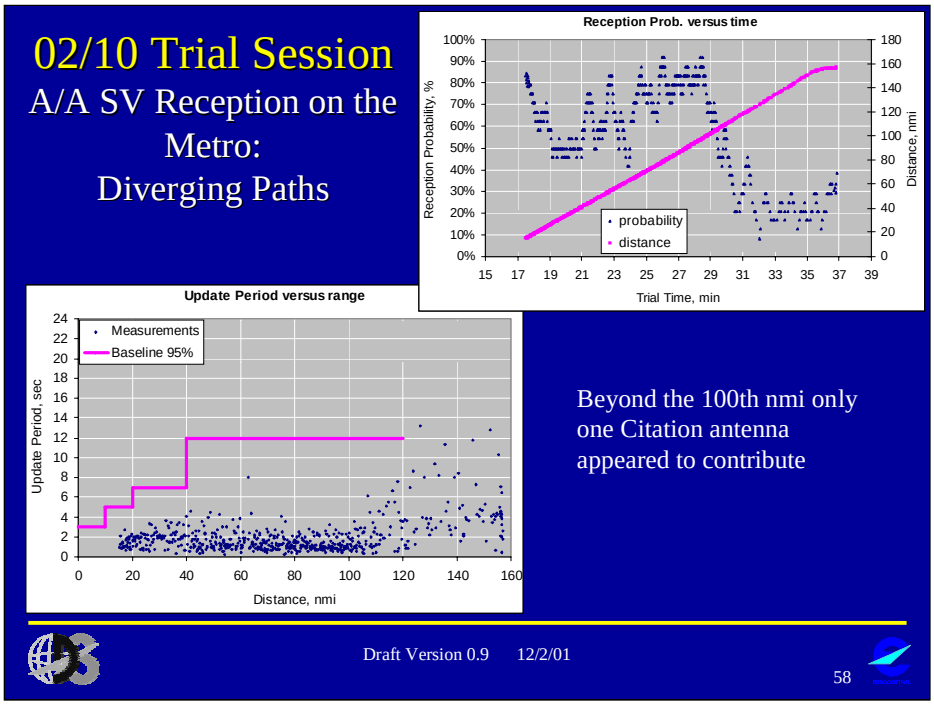
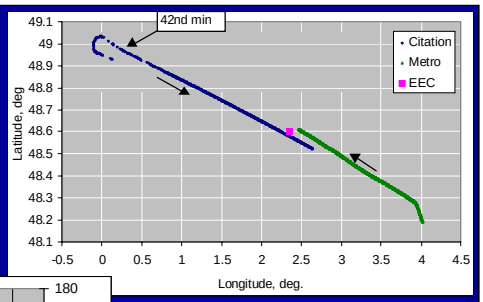
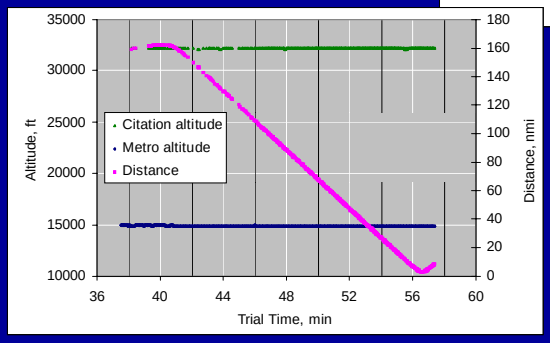


The graphs have been produced using the same calculation method ass the previous ones. Reception update intervals stay below baseline maxima up to 120 nmi.

02/10 Trial Session

A/A SV Reception on the Metro: Head to Head





The two a/c fly towards each other at constant altitudes

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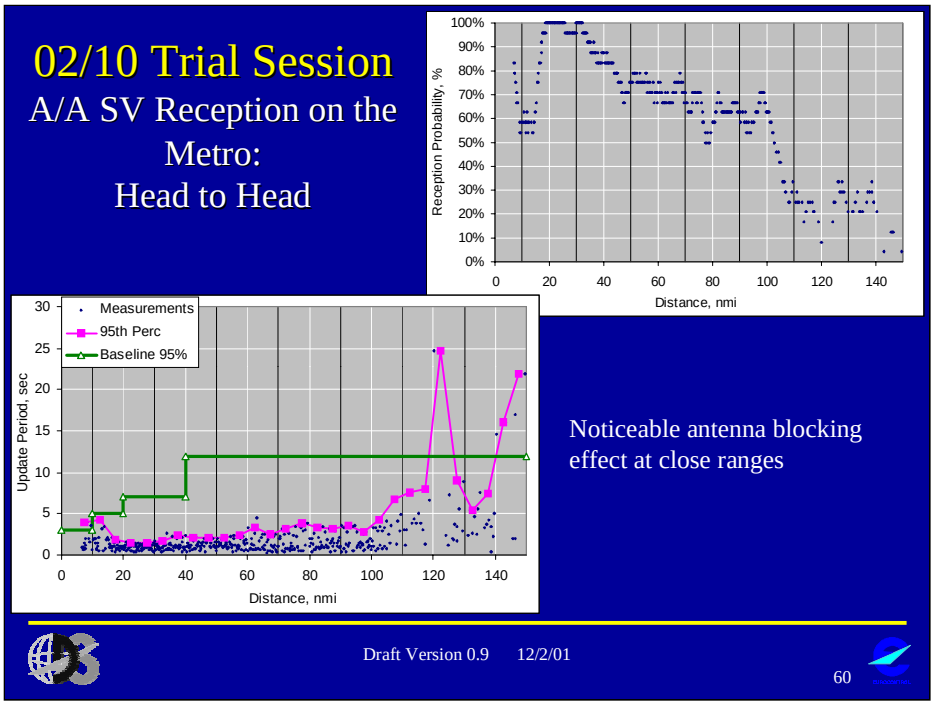
A dot is plotted for each target record in the Metro MX20 log.



These graphs have been calculated from the Metro MX20 log using the same techniques as for the previous slides.

The 95th percentile containment values have been calculated over 2 nmi wide range bins.

The observed update intervals stay below the baseline maxima up to 120 nmi, except for ranges <= 10 nmi.

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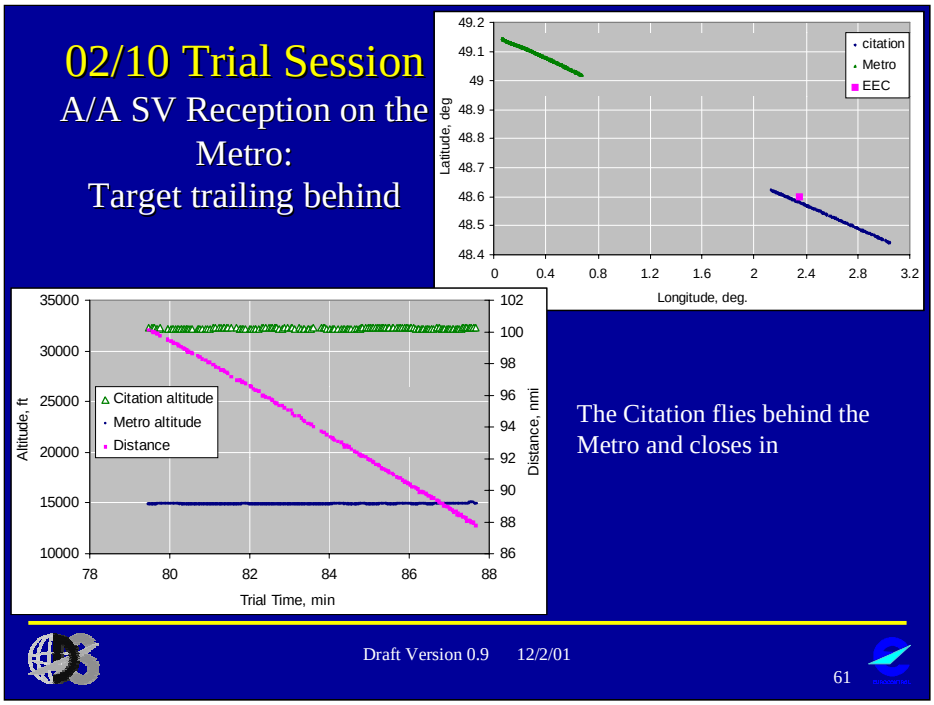

A dot is plotted for each Citation record in the Metro MX20 log. The Metro track is obtained from the own records in the Metro MX20 log.

The Citation is flying faster than the Metro hence distance is monotonically reduced with time.

Flight altitudes stayed constant.

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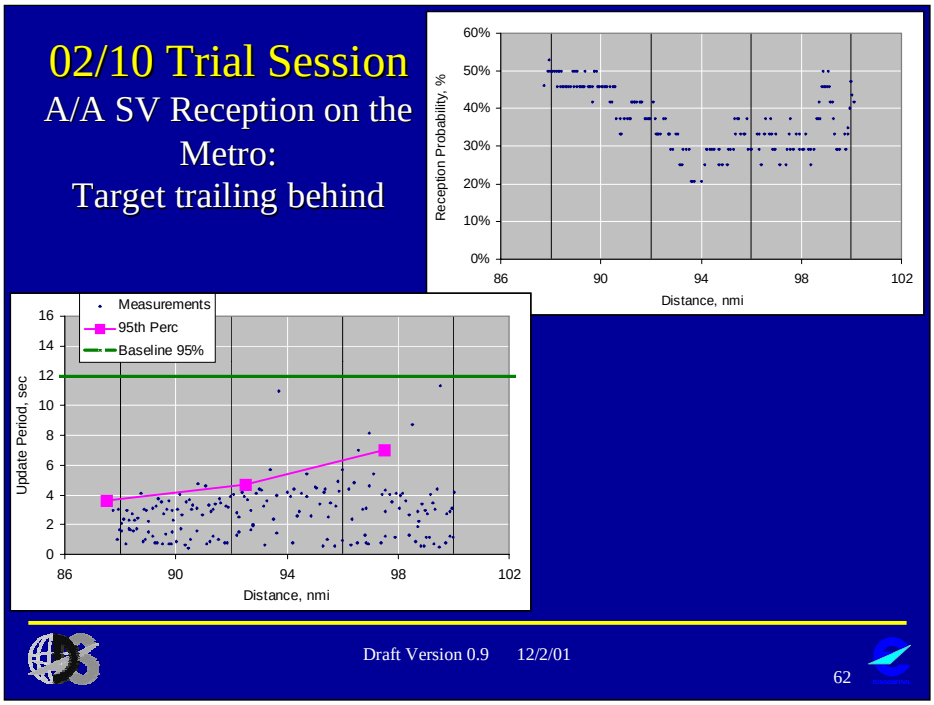

The 95th containment values have been calculated for 5 nmi wide range bins.

The DO-242 flight path deconfliction range requirement extends only to 30 nmi in the aft quadrant.

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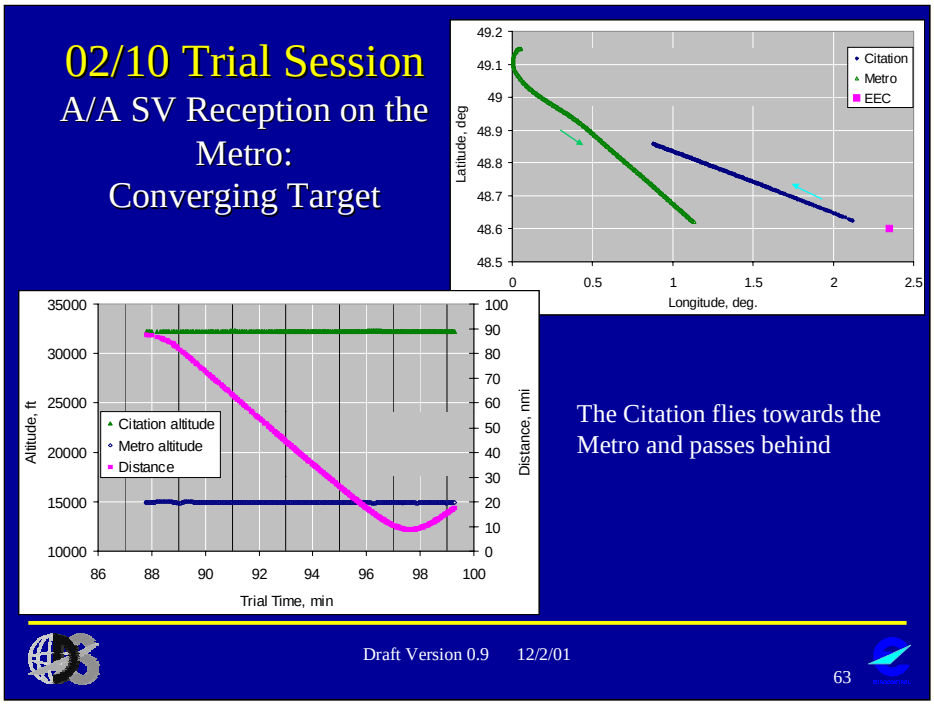

A dot is plotted for each Citation record in the Metro MX20 log. The Metro track is obtained from the own records in the Metro MX20 log.

Flight altitudes stayed constant throughout this trial segment.

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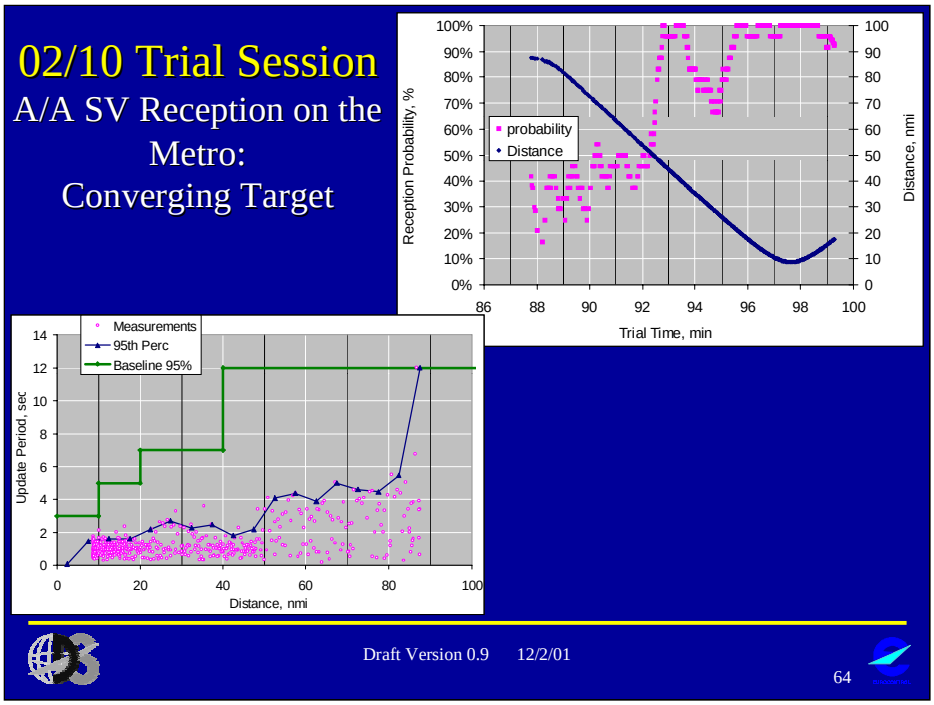

The 95th containment values have been calculated for 5 nmi wide range bins.

Update intervals remained below the MASPS specified maxim throughout the analysed period.

A noticeable increase in reception probability is observed when the aircraft separation fell below 50 nmi, which is similar to the increase observed in a previous segment (diverging paths).

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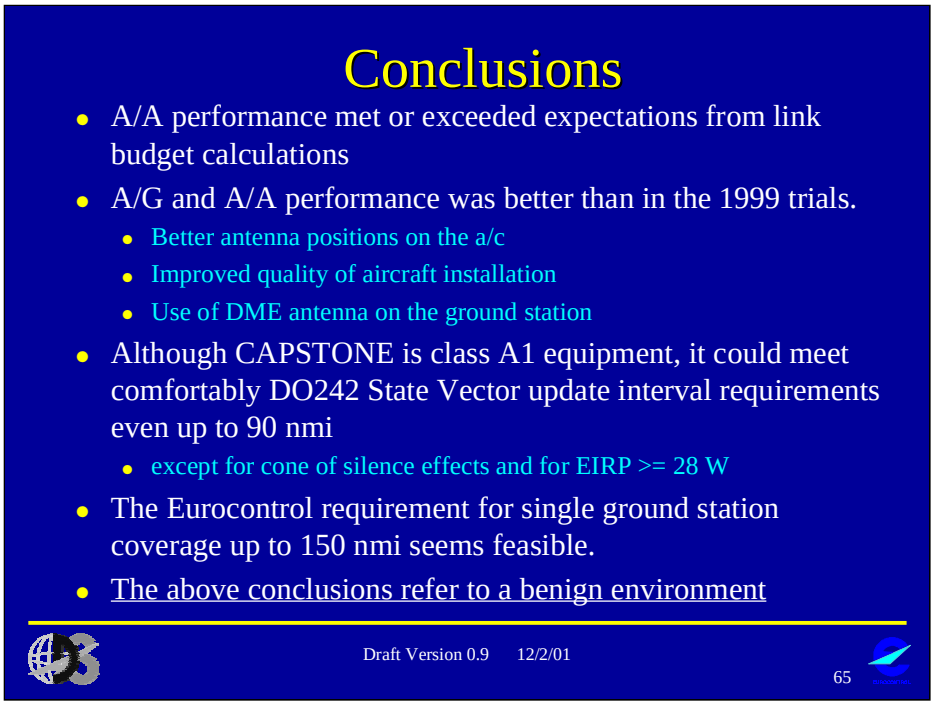

The 966 MHz channel cannot be considered representative of the likely RF interference, if UAT were to operate at a DME channel.

There were at most four UAT transmitters active at any one time, hence the trial results cannot indicate how UAT would perform with a large number of a UAT terminals.

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Next Steps

- Study top/bottom antenna effects on UAT performance
  - validate TLAT simulation antenna gain model
- Investigate efficiency of passive ranging using the TOR
  - validate the results of Chris Moody and compare with other technologies
- Assess G/A uplink performance
  - Compare with TIS-B performance requirements
- Study UAT performance on the airport surface
  - Compare with other technologies

In TLAT simulations, it has been shown that the assumed antenna gain model has significant negative impact on ADS-B performance.

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