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1 Introduction

The More Autonomous Aircraft in the Future ATM System (MA-AFAS) programme addresses the requirements of Key Action 2.4 New Perspectives in Aeronautics, Technology Platform 4. It aims to transform European research results into practical operational ATM procedures with the potential to radically improve the European Air Traffic Management (ATM) scenario in the near term (from 2005 onwards). By selecting and validating key Airborne elements of Communication, Navigation and Surveillance (CNS), and defining their economic benefits and certification requirements, the research objective is to enable more autonomous aircraft operation in the European ATM system.

This document describes the validation ground testing that was performed on the delivered MA-AFAS Avionics Package at the various trials/integration sites. This includes the testing of the different components of the system comprising of the MA-AFAS Flight Management System (MFMS) functionality, the communications elements and the intended experimental procedures for the ASAS manoeuvres. This testing was aimed at proving the compatibility of the MA-AFAS components with the external systems to which they had to be interfaced at the trials sites. Additional tests were then carried out to investigate the functional performance of the overall system in these different test environments prior to the main flight trials and ground assessment evaluations.

An overall description of the integration, verification and validation testing of the MA-AFAS Avionics Package is given in the Simulation and Flight Test Plan Document D32, Reference 1. All ground and airborne platforms are covered, including the tests involving the BAC 1-11 aircraft at Boscombe Down, the ATTAS aircraft at Braunschweig and both aircraft at Ciampino, Rome. Full details of the integration testing, verification and validation flying at these three sites are defined in separate Annexes to D32. The results from the flight trials themselves are described in the MA-AFAS Flight Test Validation Report D39, Reference 2.

2 Scope

This document is divided up based on the different locations at which the integration and ground testing of the MA-AFAS avionics package took place. At the QinetiQ sites at Bedford and Boscombe Down, this involved the use of an aircraft model test rig that simulated the motion of the BAC 1-11, the responses of the autopilot to the MFMS guidance demands and the data interfaces of the various systems onboard the aircraft. This allowed the basic functionality of the MFMS to be tested in conditions that were representative of those found on the aircraft itself. These tests were then extended to investigate the ASAS applications that were gradually implemented within the MFMS.

As well as proving the MFMS prior to the flight trails on the BAC 1-11, there were a series of pilot assessment runs that were planned using the LATCH cockpit simulator at QinetiQ Bedford. Due to delays in the development of aspects of the MFMS software, these simulator trials never actually took place, although work had been carried out to adapt the LATCH to accept the MFMS hardware. The original plan had called for the MFMS functionality to have been fully tested using the aircraft model test rig prior to the assessments in the LATCH simulator. This would also have been in advance of the final installation of the MA-AFAS equipment on the BAC 1-11 and the start of the flight trials at Boscombe Down. As it was, the MFMS ground tests eventually occurred on a similar time-scale to the installation on the aircraft and the execution of the flight trials. It was considered the level of ASAS functionality was not sufficient early on in these tests for the pilot assessments to be performed with the LATCH simulator and effort was concentrated on improving the system to support the flight trials that took place from January to March 2003.

A similar exercise was carried out at the DLR facility at Braunschweig in order to test the MFMS and ensure that it was capable of operating successfully on DLR's VFW-614 ATTAS aircraft. The trials at DLR were aimed at demonstrating the MFMS applications for airport ground movement operations, in addition to some further ASAS functions.

The testing at the Eurocontrol Experimental Centre (EEC) was concerned with the ATC controller environment and contributing to the validation of the ASAS functions. This included the application of ADS-B via the VDL Mode 4 (VDL4) data link. The EEC was participated in the ground tests of the communications application, working in conjunction with the testing performed at Boscombe Down. The EEC was also capable of providing a simulated traffic environment to support the tests of the ADS-B and TIS-B functions.

This document also covers the testing that was carried out in Rome to integrate and validate the MA-AFAS components that were installed to from the ground station and ATC controller working position. This work was managed by Alenia Marconi Systems (AMS), the ground system being transferred to the ENAV Experimental Centre for use during the Rome flight trials. These ground tests were principally related to the communications function.

3 QinetiQ Ground Tests

The primary intention of these ground tests was to develop the MFMS functionality in a simulated airborne environment and to prove the compatibility of the MFMS with the QinetiQ BAC 1-11 prior to the actual flight trials themselves.

3.1 Test Environment

An avionics development test rig, which had been used on previous occasions by QinetiQ for testing equipment before its installation onboard the BAC 1-11 trials aircraft, was adapted to support the testing of the MFMS. This test environment included a full 6-degree of freedom aircraft model, simulating the motion of the BAC 1-11 200 series aircraft. This model incorporated not only the aerodynamic behaviour of the aircraft but also the engine thrust response. There were two variations of this model that could be used, one that had the autopilot software integrated within it and another that provided the various interfaces for integrating it with the hardware autopilot box, which was identical to that on the aircraft. For the majority of the ground tests with the MFMS, the first of these versions was used, since it was more convenient for frequent test runs and was sufficiently representative of the aircraft environment to test the MFMS functionality. The latter version of the model was used prior to the initial flight tests in order to confirm that there were no behavioural differences when the real autopilot was being driven by the MFMS guidance demands. Another reason for only using the hardware autopilot for confidence testing of the MFMS was that no actual development work was expected to be done on the autopilot software and therefore it was a known factor.

The aircraft model test rig provided all the interfaces that the MFMS avionics rig would require when it was installed on the BAC 1-11. These consisted primarily of a number of Arinc 429 data bus lines and RS-232 serial connections. The other interfaces for the MFMS avionics rig were typically attached to the items of equipment that would be later installed on the aircraft along with the MFMS, for instance the track ball (or a similar device) and the MCDU. The aircraft model simulated the Arinc outputs from different avionics equipment onboard the BAC 1-11, those required by the MFMS being:

a) The Digital Air Data Computer (DADC),
b) The Inertial Reference System (IRS),
c) The Engine Instrumentation Unit (EIU),
d) The Digital Autopilot (A/P),
e) The Satellite-Based Augmentation System (SBAS),
f) The Ground-Based Augmentation System (GBAS) and
g) The Data Puddle Navigation System (DP).

This included the correct transmission speeds for the different Arinc lines (high (100kHz) or low (12.5kHz)). It had been found that because the aircraft model was simulating multiple Arinc data streams, it was not always possible to fully match the correct update rates for some of the data, principally relating to the data from the Inertial Reference System (IRS). Therefore a compromise had to be applied, taking into account the actual requirements of the MFMS in terms of the frequency of update of information and which data was actually used. This resulted in some redundant data words not being transmitted from the aircraft model relating to the IRS, GBAS and SBAS outputs and some IRS data being updated at a slightly slower rate than defined in the corresponding Arinc specification document. When the MFMS interfaces were tested on the BAC

1-11 itself, no problems were identified with having used these modified Arinc interfaces in the laboratory tests.

The ground testing also included the data link communications aspects using the MFMS avionics rig connected to the VDL4 transponder, which in turn could be linked to the experimental ground station. This allowed the component parts of the data link to be tested both independently and also connected to the full MFMS in the laboratory at Boscombe Down. The connection between the airborne transponder and the ground station transponder could be achieved either by a direct connection using an attenuator cable or by use of the VHF data link itself, i.e. free space propagation. The use of a VHF frequency had been negotiated for the VDL4 trials at Boscombe Down. Additionally, one ISDN line had been installed in the laboratory and another at the location of the ground station to be used in the Boscombe Down flight trials. This permitted testing to also be carried out with the MFMS connected through to the simulated ATC position at the Eurocontrol Experimental Centre (EEC) at Brétigny, near Paris.

A problem reporting system was set-up in support of the testing at QinetiQ in order to provide input back to BAE Systems to help with the development of the MFMS. This also provided a means by which monitoring of the problems could be maintained during the course of the various software deliveries and to track the level of development. Once BAE Systems were more directly involved in the ground testing at Boscombe Down with practically permanent attendance during the latter stages, then this local problem reporting system was generally dispensed with, being replaced by more direct input to the problem reporting system being operated by BAE Systems themselves.

3.2 Initial MFMS Delivery

Delivered - 13th June 2002

This initial delivery by BAE Systems to QinetiQ consisted of the primary hardware for the MA-AFAS FMS. This included a software release that would allow testing to start of the principal interfaces of the FMS. These consisted of the data communications with the various standard aircraft systems and the different external hardware, such as the Navigation Display (ND), the track-ball and the Multi-function Control and Display Unit (MCDU), that were to be connected to the FMS.

It was also an opportunity for the people that were due to test the system to learn about the operation of the In-House Test Platform (IHTP). The IHTP had been designed and produced by BAE Systems as a means of initially testing the FMS prior to delivery and also to support the trials and validation exercises. The IHTP provided a means for simulating external components and their different data communications with the FMS for when these physical items were not available. It was possible to configure the IHTP software when starting the system in order to select those components that were to be simulated on that particular run. For instance, it could be started with an emulation of the MCDU and another of the Display Control Panel (DCP) switches.

At this stage, there was little FMS functionality that could be accessed in this first delivery so the initial testing concentrated on verifying the correct operation of the interfaces. This also included checking that the cabling that been produced to connect the FMS to the aircraft model test rig was consistent with the delivered configuration of the FMS avionics rig.

It was found that the definition for all the FMS Arinc data channels was to expect high speed inputs, whereas the majority of the input sources were actually low speed. It was possible to update the aircraft model simulation so that all the outputs were set to high speed and this revealed that the MFMS was indicating that data was being received from the:

a) Engine Instrumentation Unit (EIU),
b) Data Puddle Aircraft Positioning System (DP),
c) Ground-Based Augmentation System (GBAS),
d) Inertial Reference System (IRS),
e) Satellite-Based Augmentation System (SBAS),
f) Digital Air Data Computer (DADC).

The Arinc interface to the MCDU was not available with this version, so it was only possible to run the IHTP emulation of the MCDU, which used ethernet for its communication with the FMU.

Another factor relating to the Arinc interface that had come to light was that the Arinc card in the FMS required any transmit channels to be assigned ahead of any receive channels in each of the two blocks of 8 channels contained on the card. This would require a wiring modification to both aircraft installation and to the cabling to the aircraft model rig, since it the original definition had the transmit channels as the last one on the first block. Fortunately, this could be incorporated before the final electrical wiring installation took place on the BAC 1-11.

The trackball, which would be mounted on the pilot's right armrest, had also been delivered by BAE Systems and the serial data output by the trackball was shown to be detected successfully by the FMS. The ND was not being produced at this point, so visual confirmation of the trackball performance was not possible. The trackball had originally been configured as a PS/2 mouse, however, BAE Systems had successfully modified the internal wiring of the trackball to operate in a serial mode.

The other key interface to be tested was the serial communications between the Displays Control Panel (DCP) and the FMS. The DCP provided the current selections for the switches related to the ND options. The FMS was currently configured to expect serial data with 7-bits, no parity and a baud rate of 9600. This was not entirely to the specification of the actual configuration of this data on the aircraft, which used even parity. The aircraft model test rig software was modified temporarily to match the FMS set-up in order to verify the decoding this data by the FMS. It was found that there were a few switch-setting configurations that were being incorrectly decoded by the FMS.

The provision of the MFMS avionics rig also allowed testing of the video output to the Navigation Display (ND) since the system was providing a test screen output. The PC cards used in the FMS avionics rig were found to only be able to provide a standard PC video signal, whereas, on the BAC 1-11, it would be required to provide an RGB-Synch signals to drive the XKD monitor that was installed in the cockpit as the ND. It was determined that an adaptor would need to be acquired to convert the video signal to the appropriate format.

3.3 Software Build A

Delivered 29th July 2002
Update A+ 7th August 2002

This software build was intended to provide a level of basic FMS functionality that would allow the system to be exercised with non-static data. This was to include the ability to use the trajectory predictor, the lateral map for the Navigation Display (ND), an element of guidance and the navigation database (the FMS incorporated a Jeppesen Arinc 424 database). It was still only possible to use the FMS with the IHTP emulation of the MCDU, communicating via ethernet, because the Arinc interface to the hardware MCDU was not fully implemented at this stage. Communication between the Flight Management Unit (FMU) and the Communications Management Unit (CMU), both of which ran on separate Power PC cards within the FMS avionics rig, was now to done by ethernet rather than by Arinc. An updated version of the IHTP software was also provided which overcame some of the problems seen with the initial system delivery.

Corrections had been made to the handling of the serial data from the Display Control Panel (DCP), the configuration of the FMS input port was now altered to accept 7-bit, even parity, serial data to match the system on the BAC 1-11 aircraft. Although the FMS was decoding this serial data with regard to the display range selections and the main display modes (lateral, vertical and taxi), other button selections were not being fully interpreted correctly. However, these problems were not really a hindrance at this stage to the progress of the testing.

The ND was able to display a lateral map mode in a rose configuration. To start with, the data on the map display was all shown as zero, but this may have been a problem with the system not identifying certain data as being valid. Once this had been sorted and data was appearing on the ND and the MCDU, it was possible to validate this information. It became clear that the ND was displaying speed parameters in the wrong units (m/s rather than knots) and that both the MCDU and the ND were using the Computed Air Speed (CAS) value instead of the True Air Speed (TAS).

The A+ software delivery provided the means to generate a simple trajectory based on a pre-defined route with Boscombe Down as the departure airport. It was possible to select the VNAV page on the MCDU and from here options were provided to load the fixed test route (<Phase Table> button), generate a trajectory based on this route (<Compute> button) and then to activate this trajectory (<Execute> button). A point-to-point route could then be displayed on the lateral map of the ND. This revealed a drawing anomaly that caused the route to become flattened on the display as the aircraft's heading became closer to either due East or due West. When the aircraft was heading due North or due South, the form of the route display appeared to be correct. The navigation data from the Inertial Reference System (IRS) was also confirmed as being read correctly in terms of parameters such as aircraft position, ground speed, track angle and heading.

A significant problem that occurred while testing this latest version concerned the IHTP system. Once the IHTP software had been running for a period of around 15 minutes, it had a serious effect on the operation of the PC with an apparent interaction with the Tornado operating environment. Effectively the whole windows environment of the PC started to operate randomly and most of the display on the PC monitor was displayed only intermittently. The only course of action was to try and close down tasks in order to recover the system.

3.4 Software Build B

Delivered 3rd September 2002
Update B+ 25th September 2002

This version of build now contained a larger proportion of communications software for running on the CMU, although there was little that could be done with regards to testing it at this stage due to FMU software developments still being required. On the FMU side, the Arinc interface to the MCDU had now been implemented and an adaptor had been purchased for converting the SVGA video output from the FMU card to RGsB signals (i.e. the Synch is combined with the Green signal). The updated software version B+ was required, however, before there was sufficient FMS functionality to start investigating the capability of generating and guiding to trajectories.

Testing of the ND using the XKD CRT monitor (as installed in the cockpit of the aircraft) could now be progressed. Initially, it was found that with the video signal passing through the adaptor unit direct to the XKD monitor, the map display appeared on the screen displaced to the left such that there was a wrap-around effect on the left-most data. However, the use of a video amplifier between the adaptor and the XKD monitor cured this shift on the display, resulting in a centralised map. This video amplifier was also already installed on the aircraft and therefore was, in any case, an element in the path to the cockpit display. The outstanding item with regard to the driving of the XKD monitor was the fact that it used a 1:1 aspect ratio rather than the more standard 4:3 aspect ratio applied by most PC-type monitors.

Prior to the Build B+ delivery, the various MA-AFAS equipment and the aircraft model test rig were transferred from Bedford to Boscombe Down. This allowed the installation and associated testing on the BAC 1-11 aircraft to proceed in parallel to the FMS functional testing in the laboratory without the need for the continual transfer of equipment between the two sites.

With the Build B+ delivery installed, it was now possible to construct routes by directly entering the waypoint names in sequence on the LEGS page of the MCDU. Only waypoints that were contained within the standard navigation database could be used since the integration of the supplementary database had not been completed. The database contained within the FMS had been limited to the UK region only in order to control the amount of memory space being used (additional memory was to be installed at a later date on the FMU and CMU PC cards to overcome this restriction). The initial trajectory had to be generated with the aircraft on the ground and would only compute the climb and cruise subphases since all the waypoints were tagged as being en-route. The FMS would only compute a descent if at least one STAR waypoint was detected at the end of the selected route.

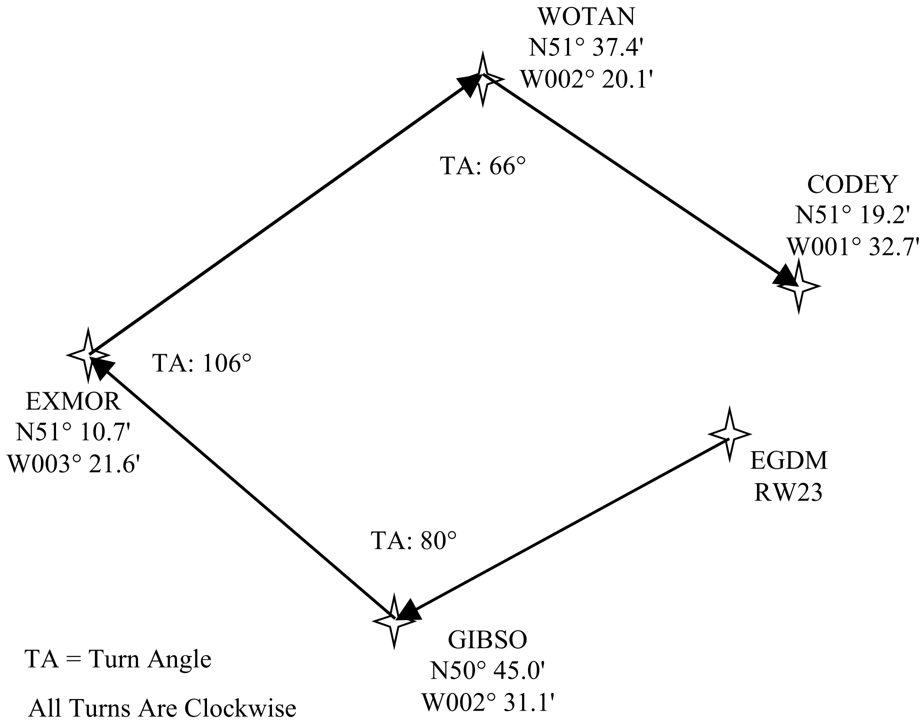


Figure 3.4-1: Route used for lab testing of Build B

The typical route that was used for these tests is shown in Figure 3.4-1. This is not shown to scale, but just gives an indication of the basic form of the route. The departure airport was set up as Boscombe Down (airport code EGDM) and the departure runway was RW23. The FMS extracted the start point details from the navigation database, using the threshold position of the departure runway as this reference point. The FMS used constant radius turns at each waypoint, the radius being set to 8nm for these en-route waypoints.

The aircraft model programme that was simulating the motion of the BAC 1-11, the various aircraft sensors and the autopilot, did not have the capability of being flown manually to simulate a take off, so it was initially configured to be in a frozen (motionless) state on the ground at Boscombe. Once the FMS had predicted a trajectory, it was possible to unfreeze the aircraft model via a control panel selection on its associated computer screen. This set the aircraft moving at a low flying speed, allowing the autopilot to be engaged and this was then used to control the aircraft, initiating a climb and accelerating the aircraft as though the aircraft had just taken off. With the aircraft heading having earlier been initialised to be consistent with that of the departure runway, it was now possible to activate the FMS trajectory. The route on the map display changed to a purple colour at this point to indicate activation of the trajectory. Guidance demands were transmitted by the FMS to the autopilot via an Arinc data bus.

Arinc Label	Parameter Description
121	Bank Demand
174	Glide Slope Deviation
301	Current Profile Mode
360	Approach Mode Prime Command
361	Height Demand

362	Computed Air Speed (CAS) Demand
363	N1 Demand
364	Next Level Height
365	Vertical Profile Gradient Change
366	Throttle Demand
370	CAS Rate Demand

Table 3.4-1: Demands Output by FMS to Autopilot via Arinc

Table 3.4-1 lists the various parameters that were output by the FMS to be used by the autopilot. Two of these, Next Level Height and Vertical Profile Gradient Change, were not actually required by the autopilot for the control of the aircraft. Of the others, Bank Demand, Height Demand, CAS Demand and N1 Demand were all consistent with the comparable labels 121, 102, 103 and 341 respectively, as defined in Arinc Spec 702. Due to historical reasons, relating to a different project, the autopilot was configured to read these particular labels rather than the standard ones, although all the scalings were identical. Label 301, the Current Profile Mode, was used to set the autopilot into the correct guidance mode, while label 366, Throttle Demand, was used only for the descent (N1 was used as thrust control parameter for the climb, while throttle position was used as the equivalent parameter for the descent). The CAS Rate Demand (label 370) provided an indication to the autopilot of the amount of thrust required for any level acceleration/deceleration. Once again, this was more of a relic from a previous project and was less relevant to the MA-AFAS FMS operation, although, as the trials showed, it could affect the performance of the autopilot. Finally, the two labels 174, Glide Slope Deviation (same as defined in Arinc Spec 710) and 360, Approach Mode Prime Command, related to the use of the FMS for precision approach trials where the glide slope could begin at a point off the centre line of the approach.

At this stage, the demands that were being output by the FMS could be monitored both by connecting a PC with an Arinc monitor programme to the output channel from the FMS and also via the aircraft model's control window on the computer screen. Although all the labels were correctly identified as being transmitted by the FMS, the data content was typically zero and therefore could not be engaged through the autopilot. The reason for this was that an error was occurring in the FMS relating to the determination of the aircraft's progress along the trajectory and thus preventing sensible demands from being derived.

3.5 Software Build C

Delivered 21st October 2002
Update C3 5th November 2002

The aim of this build was to get the trajectory generation and guidance functions working to a sufficient level that it was possible to reliably fly to the predicted flight profile, both in terms of the lateral and the vertical/speed aspects. Additional data logging had also been provided to assist in the analysis of the system performance.

The Arinc communication between the hardware MCDU and the FMS was resolved at this time. It was found that there was a configuration parameter within the MCDU itself that was incorrectly set. This permitted testing of all the hardware components that were to be installed on the BAC 1-11. It was also around this period that testing on the BAC 1-11 revealed that the serial communication from the Displays Control Panel (DCP) was not entirely consistent with the originally defined specification. It was found that rather than a string of 8 ASCII characters (7 data and 1 Line-Feed (Ctrl-J) character) being received every second from the DCP interface, there were actually 9 characters (7 data, 1 Carriage-Return (Ctrl-M) and 1 Line-Feed (Ctrl-J)). This caused a problem for the FMS, which was dependent on processing 8 ASCII characters at a time. Software modifications were carried out for the FMS and also the aircraft model simulation to replicate the actual serial data stream from the DCP. Additionally, a modification was required to ensure that the FMS correctly synchronised itself to the data stream in order to decode the characters correctly. With these changes in place, the FMS was able to successfully interpret the display switch selections.

The FMS was now able to regularly generate a trajectory using the test route shown in Figure 3.4-1 and the activation of the trajectory was working consistently, this typically being done once the aircraft simulation had passed 1000ft in the climb. With this build, the demands to the autopilot now tended to have non-zero values but still required some further modification in order to be fully compatible with the autopilot for the expected phase of flight. Although the profile mode was set to be a climb, the height demand would be zero and the CAS demand was 118kts. This latter value was due to the demand being sent as m/s rather than knots. The N1 demand was also too low, being 77% rather than the normal climb power setting of 94%. The bank demand would respond, however, in the correct sense to displacements of the aircraft from the predicted track.

It was determined that a primary problem that was influencing the demands for the autopilot was due to the FMS expecting to obtain current static air pressure data from the digital air data computer (DADC) on the BAC 1-11. However, the version of DADC installed on the aircraft (and simulated by the aircraft model programme) did not provide this data and therefore calculations of parameters such as the N1 demand were not being determined properly. By computing the static air pressure internally to the FMS, the values such as the N1 demand were now giving sensible targets for the autopilot to follow. With the additional correction to the speed demand to be knots, it was now possible to prove that the FMS could function in partner with the BAC 1-11's autopilot. It should be noted that this autopilot was not a standard version but had been built about 20 years ago to support the future ATM trials on this BAC 1-11. The autopilot therefore accepted not only the more standard FMS demands but also some non-standard Arinc labels that had allowed trials to be carried out into 4D guidance and curved precision approach procedures.

After resolving a configuration problem with the MCDU, this build had been used to prove that the FMS could be successfully integrated with the hardware MCDU for use on the aircraft. Investigations were performed into the response of the FMS to key pushes on the MCDU. Rapid key selections were not always recognised by the FMS, or at least there could be a delay in the response. However, for the majority of valid key selections and when allowing a deliberate pause between each one where an FMS action was expected, then the behaviour of the system appeared to be adequate for use in the operational trials on the aircraft.

With all the necessary hardware interfaces (apart from the serial interface to the VDL4 transponder) having been shown to function in the laboratory, the system was transferred to the BAC 1-11 in order to perform system checks on the aircraft itself and to confirm the relevant cabling was functioning correctly. With all the hardware temporarily installed on the aircraft, it was noted that data was being received on all the expected Arinc channels, including communication with the MCDU in the cockpit. The XKD monitor that was used for the Navigation Display (ND) in the cockpit, as well as the repeater in the cabin, was being driven by the FMS, although the aspect ratio still required a software update. The movement of the trackball, located on the arm-rest of the left-hand pilot's seat, was being correctly interpreted and it was only the settings of the switches for the ND that could not be read at this stage until new interface software was delivered. The modification was soon provided as a patch to the current software build and this was shown to now be fully compatible. In its present state, it was possible, however, to demonstrate that the FMS could be initialised by the pilot via the MCDU and then a route entered for which a trajectory was successfully generated. It was found, though, that the navigation data source had to be set to be the Inertial Reference System (IRS) for the time being due to some problem with the data expected by the FMS from the SBAS and GBAS equipment.

The FMS was then returned to the laboratory in order to continue the functional testing and investigate the guidance performance when integrated with the autopilot. Although the profile mode status sent to the autopilot was not always correct for the current phase of flight, providing that the altitude and speed demands were correct, the autopilot would ensure the appropriate mode (e.g. climb) was implemented. The thrust (N1) demand was also correct and therefore the autopilot was able to execute the climb to the demanded cruise altitude. The lateral guidance demands (actually just a bank angle demand) could also be engaged through the autopilot, although anticipation of the turns was not functioning properly so the aircraft would not follow the track changes at each waypoint as intended. The tests had shown, however, that this latest software build of the FMS was capable of providing the basics required for generating and then guiding to a 3D trajectory when integrated with the systems onboard the BAC 1-11 trials aircraft.

3.6 Software Build C4/C5

Delivered 25th November 2002
Update C4+ 6th December 2002
Update C5 13th January 2003

When configuring the FMS for each test run, the various data that was now being entered via the MCDU, prior to generating a trajectory, consisted of:

a) the primary navigation data source (currently still the IRS),
b) the fuel load and the zero fuel weight (in kg),
c) the company route, and
d) the cruise altitude.

The company route could be constructed off-line in a file that was part of the supplementary database for the FMS. Loading this company route therefore set up all the waypoints without having to enter them individually.

Taxi maps were also incorporated within this latest build. These maps were for Boscombe Down, Braunschweig and Rome (Ciampino) airports/airfields. It was noted that there was a discrepancy in the data for the Boscombe map since, when setting the aircraft model co-ordinates to be at the touchdown point for runway 23, the aircraft's location on the taxi map display was displaced by about 1 mile from its expected position on the runway.

Modifications were made to rectify some minor problems relating to the lateral guidance algorithms and once these were resolved, it was possible to demonstrate that the FMS could provide sensible bank demands to the autopilot to track the lateral route that had been generated. The FMS implemented fixed turn radii for calculating the lateral route for the aircraft, for these tests the default radii were set to be 3nm for SID and STAR procedures and 8nm for en-route waypoints. These defaults could be over-written, though, if a turn radius was pre-defined, especially with regard to the SID and STAR procedures.

With the current version of software, trajectories could only be generated with climb and cruise subphases due to an outstanding problem that still had to be resolved relating to the handling of the prediction for the STAR procedures. An initial trajectory would always be generated while the aircraft was on the ground, i.e. from take off, which could then be activated once the aircraft model had been set to be airborne on the departure runway track. The autopilot would be engaged in a normal climb mode before activating the FMS trajectory. The monitor screen associated with the aircraft model was used to give confirmation of valid FMS demands being received before selecting LNAV and PRFL modes on the autopilot to start using the FMS guidance. The autopilot's transition to the FMS profile (speed, altitude and thrust) demands was seen to function smoothly. Similarly, the transition to the lateral bank demand was also smooth although the magnitude of the demand could be quite large (limiting to 30°, but later this limit was reduced to 25°), being dependent on the initial cross-track error at the time of engagement. This was due to the gains in the lateral guidance algorithm being set for accurate tracking of the route, in order to ensure a tighter RNP for the ASAS manoeuvres. This influenced the initial capturing of the route, if the aircraft was displaced by 0.5nm or more, with the cross-track error being reduced more rapidly rather a gentler blend on to the route. The result was that the simulated aircraft would generally cut the route with a small opposite deviation before full capture was achieved. This might also have been a feature of the simulation, since on an initial flight test, the route capture under these conditions was seen to be smoother and therefore the roll response of the simulation was probably not exactly consistent with the real aircraft.

A revised test route was set up, this being planned to be used on the first test flight of the system. The route was a much shortened version of the intended MA-AFAS trials to be flown from Boscombe Down, this limited route remaining to the east of airway A25. The waypoints for this route are listed in Table 3.6-1.

Waypoint Name	Latitude	Longitude
RW23		
B15	N 51° 00.0'	W 002° 03.0'
AGIBS	N 50° 55.0'	W 002° 20.0'
A	N 50° 53.3'	W 002° 55.1'
B	N 51° 04.9'	W 003° 00.0'
C	N 51° 23.3'	W 002° 28.3'
D	N 51° 23.0'	W 002° 11.9'
ADSON	N 51° 03.6'	W 002° 15.2'
BD10W	N 51° 02.8'	W 001° 57.2'
EGDM	N 51° 09.2'	W 001° 45.1'
BD10E	N 51° 15.5'	W 001° 32.8'

Table 3.6-1: Co-ordinates of Waypoints for Route BOSC02

The route brought the aircraft back through the overhead at Boscombe Down from where the system could be disengaged for a manual approach to be carried out to runway 23.

Testing of this route using the aircraft model rig revealed no significant problems with regard to the FMS being able to generate a valid trajectory. Activation was also successful along with engagement of the FMS guidance demands through the autopilot. Refinement of the system was still required to ensure the correct change in the profile demands occurred at the expected positions along the route before the system could be flown for real. The determination of the aircraft's relative along-track distance from these various profile mode transition points was not always being resolved correctly and resulted in the system believing that the aircraft had progressed further along the route than was actually the case.

In preparation for the flight testing, a lap-top PC was configured to operate with the MA-AFAS FMS Avionics rig since this could be carried on and off the aircraft for the trials rather than the desk-top PC and its separate monitor that had been used for the ground testing. The lap-top PC was set-up to be identical to the desk-top PC in terms of its ethernet IP address and also its directory structure. This permitted ground testing to continue with either computer in the confident knowledge that files could be transferred between them and the system would run successfully without any additional changes. This eased some of the configuration problems that could have affected the development testing at this stage.

Also around this time, the MA-AFAS FMS rig was briefly transferred to the QinetiQ site at Bedford in order to run the FMS in conjunction with the hardware autopilot development rig that was installed there. This was to confirm that the integrated aircraft model and autopilot software simulation that had been currently used for the testing was providing an accurate reproduction of the behaviour of the real autopilot. These tests proved that the actual hardware version of the autopilot had the same basic characteristics when following the FMS guidance demands as the software simulation version. During these tests, however, there was a problem encountered in relation to the Arinc data being received by the FMS, causing a failure in the system after about 30 to 40 minutes of operation. Subsequently, having returned the MA-AFAS equipment to Boscombe Down, a replacement Arinc card was installed into the FMS avionics rig. No further instances of the problem seen at Bedford were encountered either in laboratory testing or during the flight trials themselves.

Just prior to Christmas, secondary ground testing of the MA-AFAS equipment on the aircraft had now highlighted that there was a wiring fault with the Arinc line from the FMS to the autopilot. This required a minor wiring modification to an aircraft cable connected to the FMS avionics rig. Although this was completed rapidly and tested successfully, it also required an update to the aircraft clearance paperwork, which meant that the first flight could not occur until the New Year.

Directly before the first flight took place on the 14th January 2003, a further software update was received, this having been classified as Build C5. A successful test was performed using the ground test rig and the proposed flight trials route (referred to as company route BOSC02). This incorporated a take off and climb to a cruise altitude of FL240, with a speed transition during the climb from 230kts to 250kts CAS and a further acceleration to 260kts CAS once the cruise level had been reached. The lateral route consisted primarily of a series of right-hand turns with two left-hand turns towards the end. These were all flown without problem with the autopilot in LNAV mode using the FMS bank demand. The profile demands were used until the aircraft had reached waypoint C in the cruise, at which point a descent back to FL50 was initiated directly through the change altitude mode of the autopilot. A test performed on the aircraft itself also confirmed that this latest version of the software was able to use data supplied by the SBAS and GBAS equipment, the intention being to use the SBAS as the position data source during the flight (see Flight Trials Report, D39, for the account of the actual flight).

Following on from the first flight, further work using the aircraft model test rig revealed that certain subphase details were not being updated within the FMS when it detected that the next transition point had been reached and this had been influencing the system's performance. Some local software modifications were tested to prove that the correct profile demands were now being updated properly and that the subphases were being tracked sequentially along the route.

3.7 Software Build D1

Delivered 20th January 2003
Update D1+ 24th January 2003

This version of software provided various modifications and improvements in the system functionality. These included:

- The ability to reboot the system in the air while retaining the current active trajectory data so that it does not have to be re-entered;
- The selection of SIDs and STARs on the MCDU when setting up the route to be flown;
- The display of the curved turn path at each route waypoint on the lateral map;
- Updated taxi map for Boscombe Down;
- The vertical profile display for the ND;
- The ability to define 3 types of turn for a waypoint, these being fly by, turn after and turn arc;
- The use of UTC derived from the GBAS/SBAS data inputs to synchronise the time in the FMS;
- The specification of a take-off time when generating on the ground;
- The inclusion of the communications manager software;
- The addition of the surveillance database for the handling traffic reports, allowing the ASAS functionality to be tested;
- The ability to run an emulation of the MCDU on the IHTP PC to monitor the use of the hardware version of the MCDU.

After some refinement of a few parts of this latest delivery, it was possible to run the FMS around a full flight profile using the company route, BOSC05, with a continuous climb to FL240 followed by a descent down to FL40. The waypoints that made up BOSC05 were essentially the same as those for BOSC02, but in the reverse direction in order to proved a better lateral transition into the STAR, STR23, that was defined to be the south of Boscombe Down. The co-ordinates for these waypoints are shown in Table 3.7-1, including whether they were classified as being a SID, STAR or En-Route (E/R) waypoint.

Waypoint Name	Type	Latitude	Longitude
RW23	SID	N 51° 09.7’	W 001° 44.1’
BD10W	SID	N 51° 02.8’	W 001° 57.2’
ADSON	E/R	N 51° 03.6’	W 002° 15.2’
D	E/R	N 51° 23.0’	W 002° 11.9’
C	E/R	N 51° 23.3’	W 002° 28.3’
B	E/R	N 51° 04.9’	W 003° 00.0’

A	E/R	N 50° 53.3’	W 002° 55.1’
AGIBS	E/R	N 50° 55.0’	W 002° 20.0’
DM005	STAR	N 51° 02.8’	W 001° 57.2’
DM001	STAR	N 51° 09.2’	W 001° 45.1’
DM002	STAR	N 51° 15.5’	W 001° 32.8’

Table 3.7-1: Co-ordinates of Waypoints for Route BOSC05

Although a trajectory could be generated and then guided to, the predicted altitude profile was rather shallow for the descent (see Figure 3.7-1) compared with the expected performance for the BAC 1-11. The FMS trajectory generation used a constant N1 setting as the thrust control for the descent rather than the idle throttle position. In carrying out the tests, it was found that the N1 demand for the descent was 77%, which was then converted to a throttle position demand for transmission to the autopilot. The result was that the throttle demand steadily increased from an initial demand of about 5º as the aircraft descended in order to maintain the N1 value. Despite this, the descent profile that this created was still noticeably steeper than that predicted. The estimate was that the predicted height rate was about half of what it should have been to match the descent of the BAC 1-11. In the test using the aircraft rig, by the time the aircraft had reached waypoint DM001 (equivalent to an along-track distance of 140nm) it had descended to just above 4000ft. The FMS guidance process had tracked the predicted speed profile as planned, with the demand requesting the initial acceleration to 230kts CAS followed by a further increase during the climb to 250kts and then 260kts once the aircraft was in the cruise. Just prior to the start of descent, the demand reduced back to 250kts CAS, which was maintained throughout the descent, although there would have been a further deceleration at 10000ft to 230kts, but the prediction finished at 14000ft.

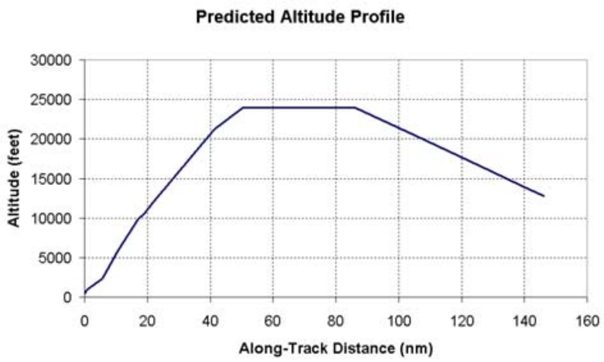


Figure 3.7-1: MFMS Predicted Altitude Profile

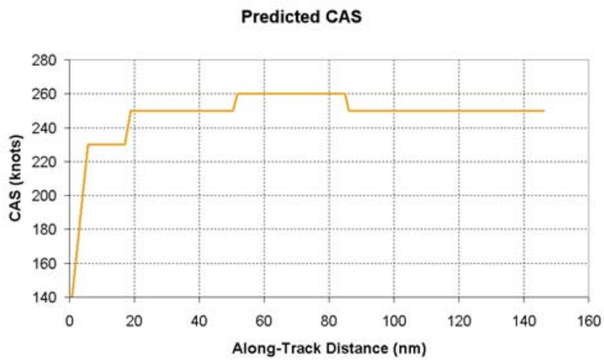


Figure 3.7-2: MFMS Predicted CAS Profile

To ensure that the BAC 1-11 would have completed its descent to FL40 by the time it had reached waypoint DM005 (along-track distance of 130nm), it was decided to use a lower cruise altitude of FL210. The standard method for initialising the FMS via the MCDU and setting a test run going had now reached a stage at which it essentially remained the same for the remainder of the trials period, both for the ground and airborne testing. This process consisted of entering the following data using the MCDU once the FMS software had been downloaded and the system started, resulting in the Menu page appearing on the MCDU:

- Select the Nav Source (normally SBAS when using the ground-based test rig),
- Enter the Fuel Load and Zero Fuel Weight,
- Enter the Departure and Arrival Airport Codes (e.g. EGDM for Boscombe Down),

- Select the Company Route from the options provided by the FMS for the flight between these two airports,
- Enter the departure runway and then select the appropriate SID,
- Enter the Arrival runway and select the expected STAR,
- Remove the discontinuities on he LEGS page between the waypoints at the end of the SID and the start of the en-route section and between the end of the en-route section and the start of the STAR,
- Enter the cruise altitude,
- Enter the Estimated Off-Blocks Time (EOBT) and the Calculated Take-Off Time (CTOT),
- Generate (LOAD) the trajectory,
- Activate (EXECUTE) the trajectory once the aircraft is lined-up on the runway (standard initialisation position when using the aircraft model rig).

3.8 Software Build D2

Delivered 3rd February 2003
Update D2+ 10th February 2003

One of the main additions contained within this build release was the ability to perform lateral pass behind of a nominated target aircraft, this being one of the delegated ASAS manoeuvres that was to be flown with the trials aircraft. In association with this, the software build also contained improvements to the way the FMS performed in-flight trajectory generations. Additionally, the FMS incorporated a dummy surveillance database that could be used for testing purposes in place of the standard surveillance system that required external traffic reports to be received via the communications management unit (CMU).

Other areas in which improvements had been made with this build were:
- Format and readability of information on the Navigation Display (ND),
- The handling of time constraints by the trajectory predictor,
- The communication interface with the MCDU to reduce the number of missed key presses,
- The correct interpretation of the UTC data output by the SBAS/GBAS equipment.

For testing of the lateral pass-behind manoeuvre, the dummy surveillance database required a file to be set up that contained data defining a simple trajectory for the target aircraft. This file, Scenario.txt, could contain information on more than one aircraft, so that a number of situations and conflicts could be created for a single test route. The first value in the file was the total number of simulated aircraft referenced in this file. The remainder of the file contained entries for each of these aircraft, the standard format for each entry being as follows:

`24000`	-- altitude of the aircraft (in feet)
`300`	-- ground speed of the aircraft (in knots)
`3`	-- number of trajectory route points for this aircraft
`N51442732W003242428`	-- lat./long. co-ordinates for point 1
`N50581980W002413819`	-- lat./long. co-ordinates for point 2
`N50145432W002025113`	-- lat./long. co-ordinates for point 3

For the first tests, the ground speed of the target aircraft was set to be 1kt in order to ensure that the target aircraft could be placed at the required position along the route for the conflict situation at the appropriate time. Since the simulation of the target aircraft began once the FMS process had fully started, it would otherwise have been difficult to synchronise the two aircraft to arrive at the same place at the same time. This allowed the basic process to be checked using the test route shown in Figure 3.4-1. The dummy surveillance database also simulated the expected ADS-B update rate by re-computing the position of the target aircraft once every 3 seconds.

The simulated aircraft, identity SIM00, was configured to intercept the track of the BAC 1-11 on the leg between waypoints EXMOR and WOTAN. This intercept point was located two-thirds of the way (about 30nm) from EXMOR to WOTAN and the aircraft SIM00 was on a track at 90º to that of the BAC 1-11, crossing from left to right. A restriction on when the pass-behind trajectory could be generated was that the host aircraft (in this case the BAC 1-11) had to be on the track towards the intercept point between the two aircraft. The reason for this was that the manoeuvre generator within the FMS based its calculations on the relative tracks between the two aircraft at the moment when the prediction is requested by the pilot (i.e. it is working out the closest point of approach given the current conditions).

Using this configuration and following a few refinements, it was demonstrated that the FMS was capable of generating a pass-behind manoeuvre while flying this test route. The information to select the target aircraft and set the minimum allowed spacing distance between the two aircraft was entered via the ASAS menu pages on the MCDU. An additional entry that was made via the MCDU was the waypoint at which the aircraft was required to resume its original route (in this case waypoint WOTAN). This information would be expected to be relayed from the air traffic controller, either by R/T (the pilot would enter it manually through the MCDU) or by data link (it would then be inserted automatically into the FMS for the pilot to review via the MCDU and ND). For these first tests, a spacing distance of 8nm was used and a trajectory was successfully generated once the BAC 1-11 had completed the turn at EXMOR.

At this point, the tests were done under ISA and zero wind conditions to verify the basic performance of the system. The results from one test show that a trajectory was generated when the BAC 1-11 was 19nm (approximately 4.25 minutes) from the intercept point. The target aircraft, SIM00, was about 0.4nm from intercepting the track of the BAC 1-11 when the pass-behind was predicted. The resultant trajectory deviated the BAC 1-11 by 10.8nm to the left of its original track. The technique used by the FMS in computing this type of manoeuvre was to determine a new initial track (in this case a track change of 33º) in order to achieve a point of closest approach equivalent to the minimum spacing distance plus a tolerance factor of 0.25nm. It would then insert a further turn to first briefly parallel the original track before a final turn was added to head directly to the resume waypoint, WOTAN. The FMS also incorporates other thresholds in its computation so that, providing the separation is not significantly greater than the minimum value of 8.25nm, then the solution would be acceptable. Hence, the very minimum deviation from the original track that the system could possibly have produced for this situation would have been of the order of 9.5 to 10nm. This trajectory is displayed to the pilot both on the lateral map display of the ND and on the MCDU and, providing the pilot is satisfied with the solution, he/she then activates it. This was done successfully on the test run and the FMS guidance process followed this new route.

Having proven the basics of the execution of a pass-behind manoeuvre, an implementation was tested that could be used during the next flight test. Once again, a target aircraft was set up with a speed of only 1kt to limit the number of variables during the flight trial. The route to be used was the same as that described in Table 3.7-1, with the target aircraft on track crossing the leg between waypoints A and AGIBS. This was problematic, however, because there was insufficient track distance between the end of the turn at A and the conflict with SIM00 in order to always be able to insert a lateral pass-behind manoeuvre. The target aircraft was consequently moved to be about 4nm beyond waypoint AGIBS on the leg to DM005. Since the track change at AGIBS was quite small on this route, there was less of a problem in generating the pass-behind manoeuvre while the BAC 1-11 was on the leg towards AGIBS because the tracks of the two aircraft would still cross in a similar location. This would effectively mean that the pass-behind manoeuvre would miss out waypoint AGIBS since DM005 would be the 'resume at' waypoint.

The main difference from the previous test was that the BAC 1-11 would be descending during the section of the flight where the pass-behind was to occur (the first tests had occurred in the cruise). The ground rig tests were to ascertain whether it would be possible for the FMS to determine a sensible lateral manoeuvre under these conditions. It was found that a trajectory could be generated although the original speed change subphase at 10000ft was moved to 4000ft to coincide with the level entry into the STAR. The reason for this was that the manoeuvre generator assumed a constant ground speed initially for the BAC 1-11 in order to define time constraints at each of the lateral change points, ensuring that the aircraft would be at the correct spacing at the correct time. Due to the aircraft being in the descent, the ground speed was actually reducing and therefore the predicted manoeuvre also included an increase in the speed demand of 7kts in order to meet these time constraints. However, the lateral path was computed satisfactorily, using a minimum spacing distance of 5nm, and the FMS was able to guide the aircraft along this modified route. This performance was then repeated with the actual aircraft in a flight test the following day.

With the basic elements of the FMS now shown to be working with a reasonable level of confidence in its performance, the testing reverted to using the main trials route that would be flown from Boscombe Down. The MFMS company route name was QNQ1 (see Table 3.8-1) and this route incorporated trials areas which had been agreed with the local ATC for the aircraft to perform testing of various delegated ASAS manoeuvres. The tracks for a number of simulated aircraft were created that would allow four separate pass-behind manoeuvres to be tested. Later, additional traffic was included for the testing of two merge-behind situations with a modified version of this route.

Rather than having the simulated aircraft being almost static as was the case in the initial tests, these aircraft was set up with a ground speed that was comparable to that of the BAC 1-11 in the cruise. Then, to ensure that these aircraft would cross the route of the BAC 1-11 at the right time to cause the required conflict situations, the simulation within the surveillance database of the MFMS was configured to trigger automatically. This monitored the progress of the BAC 1-11 and once it was in the cruise and had passed a particular point on its route, the simulation of the target aircraft was started. Each simulated aircraft had a unique identity, SIMxx (where xx could be from 00 to 27) and the locations of the four pass-behind manoeuvres were:

1. On the leg between waypoints EEE and FFF with aircraft SIM00,
2. On the leg between waypoints GGG and HHH with aircraft SIM02,
3. On the leg between waypoints III and JJJ with aircraft SIM03,
4. On the leg between waypoints JJJ and ZZZ with aircraft SIM04.

All of these pass-behind manoeuvres were performed in the cruise at FL240. The simulated target aircraft SIM00 and SIM03 were set up on tracks that were around 80 to 90º relative to that of the BAC 1-11. The other two aircraft were configured to be on tracks that had a shallower convergence (about 40 º) to the track of the BAC 1-11, SIM02 flying in a similar direction to the BAC 1-11 while SIM04 was on a more opposing track to the BAC 1-11. Typically, these pass-behind manoeuvres were computed when the BAC 1-11 was about 3.5 minutes from reaching the intercept point between the tracks. This tended to relate to the standard 5nm minimum separation between the aircraft being breached approximately 3 minutes ahead of the BAC 1-11's current position.

Waypoint	Lat/Long (WGS84)	Waypoint	Lat/Long (WGS84)
EGDM	N51º 09.13' W001º 44.84'	PPP	N51º 13.00' W003º 38.00'
ESPIN	N51º 07.30' W001º 48.20'	QQQ	N50º 24.50' W004º 22.00'
WOLF	N51º 04.40' W001º 47.10'	RRR	N50º 25.00' W004º 39.50'
INGL	N51º 03.20' W001º 42.30'	HHH	N50º 26.00' W005º 01.80'
KATE	N50º 58.60' W001º 43.10'	SSS	N50º 42.50' W005º 11.00'
XXX	N50º 53.63' W002º 50.39'	TTT	N51º 20.00' W004º 16.00'
BBB	N51º 04.90' W003º 00.00'	ZZZ	N51º 24.39' W003º 48.26'
YYY	N51º 23.25' W002º 55.21'	KKK	N51º 24.80' W003º 32.80'
DDD	N51º 23.00' W002º 28.30'	CCC	N51º 23.30' W003º 00.00'
EEE	N51º 12.50' W002º 11.90'	AAA	N50º 53.30' W002º 55.10'
FFF	N50º 44.60' W003º 10.00'	AGIBS	N50º 55.00' W002º 20.00'
GGG	N50º 46.60' W003º 46.80'	DM005	N50º 59.87' W001º 42.75'
HHH	N50º 26.00' W005º 01.80'	DM001	N51º 06.17' W001º 30.74'
MMM	N50º 50.00' W005º 13.00'	DM002	N51º 13.10' W001º 29.09'
JJJ	N51º 23.10' W005º 07.80'	BD10E	N51º 16.21' W001º 32.30'
ZZZ	N51º 24.39' W003º 48.26'	EGDM	N51º 09.13' W001º 44.84'

Table 3.8-1: Waypoint Positions for Route QNQ1

Some initial problems were encountered with the time constraints that were being assigned by the MFMS to the manoeuvre waypoints, which it had created to form the lateral pass-behind of the target aircraft. The MFMS was normally determining valid positions for these manoeuvre waypoints to ensure the necessary spacing distance, but for certain configurations, it was determining a negative time difference from one manoeuvre waypoint to the next. This time difference was being used to set the associated time window at each waypoint and consequently the trajectory prediction process was unable to satisfy these time constraints. Once this was resolved, the different pass-behind manoeuvres were being consistently completed successfully under zero wind and ISA conditions.

3.9 Software Build D3

Delivered 17th February 2003
Update D3+ 24th February 2003

The Build D3 version of the MA-AFAS software provided additional functionality for performing merge-behind manoeuvres using distance as the spacing parameter (the system was also intended to be able to use time as the spacing parameter). In this case, it would be possible to define the target aircraft via the MCDU and then assign the waypoint at which the own aircraft should be at a specified distance behind the target aircraft. A key requirement for this type of manoeuvre is that the two aircraft must be following the same planned route from the merge waypoint onwards. The own aircraft should then remain at this set distance behind the target aircraft until instructed by ATC. It was possible to enter via the MCDU the waypoint at which this manoeuvre was to be considered as complete.

Additional functionality that was incorporated within this build and its update was concerned with the precision approach capability. This would allow the MFMS to automatically control the transitions to the approach mode of the autopilot. It would also generate a glide slope deviation signal that replicated that of an ILS, this data being transmitted by Arinc data bus to the autopilot and being consistent with label 174 in Arinc specification 710 for onboard ILS equipment. This would mean that the aircraft could fly a non-standard routeing on to the localiser with the start of the glide path not necessarily being on the localiser centre line. The autopilot would follow the normal lateral guidance demands from the MFMS until it was effectively on the localiser centre line, but could also follow the glide slope deviation signal from the MFMS while still making the turn on to the final approach. Once on the centre line the autopilot would transition to directly use the localiser and glide slope signals from the selected approach guidance system (in this case it was to be the GBAS rather than the ILS on the BAC 1-11). The result would be that approaches could be flown which captured the localiser centre line only 4nm, for instance, from the touch down point.

At the same time as this delivery was made, a second MA-AFAS avionics rig was delivered to Boscombe Down in order to assist in the development process. This would permit the data link communications testing to be carried out in parallel to that of the other MFMS functionality while also allowing ground testing to continue while the main MA-AFAS rig was installed on the BAC 1-11 for the flight tests.

For the testing of the merge behind function, a modified version of the test route shown in Figure 3.4-1 was produced that extended further to the west. This consisted of the en-route waypoints listed in Table 3.9-1, a simple SID being flown out of Boscombe Down in order to reach GIBSO at FL150.

Waypoint Name	Latitude	Longitude
GIBSO	N50° 45' 00.00"	W002° 31' 06.00"
EX	N50° 45' 08.00"	W003° 17' 42.00"
DAWLY	N50° 34' 24.00"	W003° 27' 48.00"
SMG	N50° 26' 06.00"	W005° 01' 48.00"
CHVNR	N51° 05' 00.00"	W004° 09' 00.00"
EXMOR	N51° 10' 42.00"	W003° 21' 36.00"
WOTAN	N51° 37' 24.00"	W002° 20' 06.00"
CODEY	N51° 19' 12.00"	W001° 32' 43.00"

Table 3.9-1: Route used for Initial Testing of Merge Behind Function

A simulated aircraft was defined to be on track of 293º True towards waypoint DAWLY, from where it would continue on the same route as the BAC 1-11 towards SMG. The ground speed of the target aircraft was set to be constant at 322kts, equivalent to an approximate air speed of 260kts CAS at FL150 under ISA conditions. The intention was to generate the merge-behind manoeuvre when the BAC 1-11 was on the leg from GIBSO to EX with the 'merge-at' waypoint entered as

DAWLY and a required spacing of 5nm. When predicting the merge-behind manoeuvre, the MFMS would apply an additional threshold value to the specified spacing distance to allow some tolerance in the system's ability to accurately predict the movements of both aircraft. The MFMS should then generate a direct track from the aircraft's current position to DAWLY and it should also determine a revised speed profile in order to reach DAWLY at the estimated time to place it 5nm plus the threshold distance behind the target aircraft, SIM10. At this stage of development, the additional threshold distance amounted to 2nm, although a future software update modified the way this was determined and in later tests it was only 0.25nm.

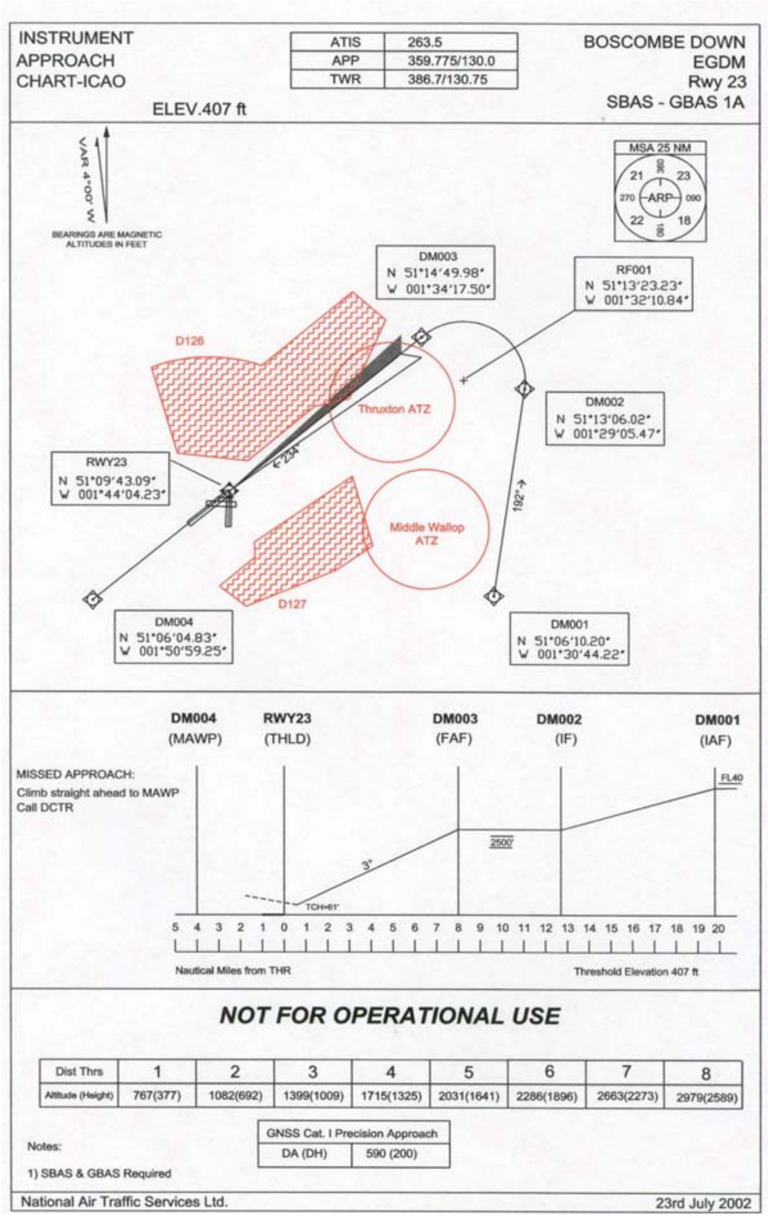
From the testing of the merge behind manoeuvre using this set up, it was found that the MFMS was able to predict a trajectory involving a go-direct to DAWLY, which the aircraft then followed once it was activated. The turn that was inserted ahead of the aircraft tended to be too close, however, so that the aircraft had to perform a greater turn to correct back on to this new track. The actual track change was of the order of just over 20º, with the BAC 1-11 being about 25.5nm on a direct track from DAWLY. The MFMS had also estimated that the BAC 1-11 would be about 2nm behind the target aircraft at DAWLY if it continued at its current speed. Therefore it determined a revised speed profile of 220kts CAS, in order to ensure the necessary spacing, the MFMS determining that the target aircraft would be (5+2)nm past DAWLY at 1515:16 and its resultant trajectory for the BAC 1-11 now gave an ETA at DAWLY of 1515:12. The predicted speed then increased to 260kts CAS after DAWLY in order to match the estimated speed of the target aircraft. The insertion of these additional speed subphases was not entirely consistent with the normal way speed changes were handled elsewhere in the trajectory structure and consequently the guidance function was not interpreting this data correctly. Hence, at this stage, the updated speed demands were not being passed by the guidance function through to the autopilot and thus the spacing distance was not being achieved as planned.

This version of the MFMS software was also used to test the guidance performance for the precision departure route that had been devised for Boscombe Down. This was associated with runway 23, an S-shaped route having been defined with the start of the first turn being 2nm from the far threshold of runway 23 (i.e. from the threshold of runway 05). The initial turn was 125º to the left with a constant radius of 2nm, this then being followed by a straight segment of just over 3nm and a further turn of 160º to the right, this time with a constant radius of 2.5nm. With the trajectory being activated while the aircraft was on the runway, the guidance output to the autopilot was triggered once the aircraft was climbing away from the runway and the lateral guidance demands could be engaged through the autopilot with sufficient time before the first turn. No guidance problems were encountered and the MFMS was able to accurately track the aircraft along this curved departure route. This simulated the FMS using a local-area differential GNSS (in this case the GBAS) as the source of position data in order to achieve the necessary guidance precision for a more complicated departure profile. This was subsequently tested on the next trials flight on the 27th February during which the precision departure route was successfully flown, the guidance process behaving as expected from these ground tests.

The implementation for the precision approach capability had also required a few software modifications to the BAC 1-11 autopilot in order for it to accept the relevant control mode data from the MFMS. The application of the precision approach function consisted of the MFMS first predicting the flight profile that included the vertical profile that was to be flown within the STAR leading to the aircraft being at the assigned altitude for intercepting the glide slope. The glide slope angle could be specified in a parameter file, the intention being to test both 3º and 4.5º approaches.

The complete lateral path was also determined to the approach runway threshold. The MFMS would provide lateral, vertical and speed guidance demands to the autopilot throughout the flight, just as it would normally. However, once the aircraft had passed the STAR entry point, an extra bit was set by the MFMS in the guidance control mode word (Arinc label 301) that it sent to the autopilot. This allowed the pilot to disengage the speed control from the MFMS by directly selecting a new speed demand via the autopilot control panel, although the MFMS continued to provide the vertical guidance demands to the autopilot. This meant that the pilot could set the speed required for the current flap and undercarriage configuration during the approach. The autopilot would also accept localiser and glide slope prime commands from the MFMS and therefore it would automatically transition to use these guidance demands from the approach system (GBAS) once it had determined that the various capture conditions were satisfied. The autopilot would only use the glide slope deviation data from the approach guidance system if the localiser had already been captured, i.e. the aircraft is effectively on the approach centre line. If this was not the case, the autopilot would use the glide slope deviation data output by the MFMS for guidance purposes until the localiser was captured. This would allow curved approaches to be flown.

The initial ground testing of this precision approach function was to ensure that the correct transitions occurred in the control mode information sent by the MFMS to the autopilot and that the autopilot was correctly interpreting this data. A simple approach route (see Figure 3.9-1) was used, the BAC 1-11 following a STAR to the south of Boscombe Down that led to a final extended turn at waypoint DM002. This brought the aircraft on to the approach centre line for runway 23 at a distance of 8nm from the runway threshold and from where it was to capture a 3º glide slope. The aircraft was to be at a height of 2500ft agl (above ground level) when it intercepted the glide slope. The MFMS used the GBAS equipment as its primary position source operating within the STAR and it also made use of the height data from the GBAS in its calculations of the glide slope deviation. Although the GBAS was supposed to output a height value referenced to mean sea level (msl), the actual GBAS equipment on the aircraft was calculating the height referenced to the WGS-84 ellipsoid. This meant that an additional correction factor of 49.54m (162.53ft) had to be applied within the MFMS to convert the received data to be above msl. Additionally, it had also been identified that the time reference from the GBAS equipment was GPS time rather than the expected UTC value and consequently a correction of 13 seconds had to be applied by the MFMS to this data as well.

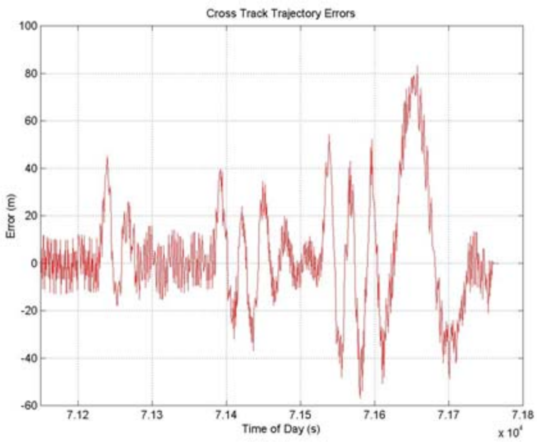


Dist Thrs	1	2	3	4	5	6	7	8
Altitude (Height)	767(377)	1082(692)	1399(1009)	1715(1325)	2031(1641)	2286(1896)	2663(2273)	2979(2589)

GNSS Cat. I Precision Approach	
DA (DH)	590 (200)

Figure 3.9-1: Initial Route used for Testing Precision Approach Function

After a few iterations and modifications to the MFMS software and the autopilot logic, it was possible to demonstrate that the transitions in the various autopilot control mode states were being triggered by the MFMS. Autopilot speed control could also be taken over by the pilot once the aircraft was in the STAR without disengaging the vertical guidance demands from the MFMS. There was a noticeable delay in the change in demand from the MFMS for a descent from FL40 to 2500ft, but this did not directly affect the basic testing of this function. It was actually with the Build E1 version of the MFMS software that a fully coupled approach could be demonstrated with the aircraft model test rig. In this case, the MFMS guided the aircraft laterally through the STAR. Figure 3.9-2 and Figure 3.9-3 show the type of performance that was achieved using the FMS lateral guidance demands, the flight technical error for the cross-track deviation being within 60m as the aircraft progressed through the STAR.



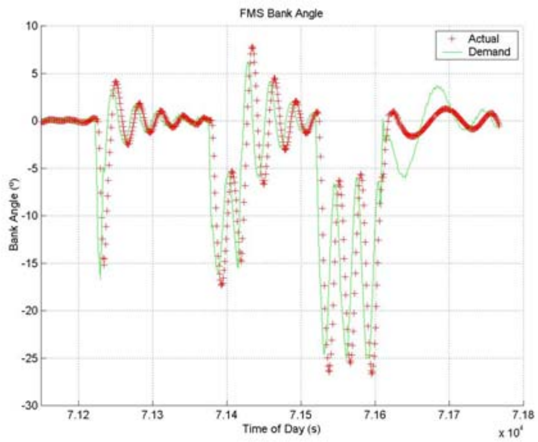
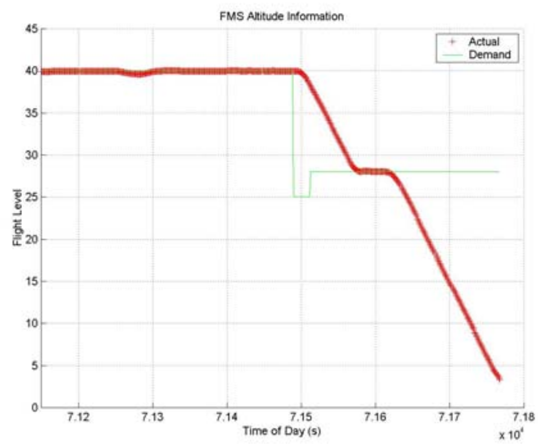


Figure 3.9-2: Cross-Track Error during Testing of Precision Approach Function

Figure 3.9-3: Demanded and Actual Bank Angle during Testing of Precision Approach Function

As the aircraft neared waypoint DM003 at the completion of the final turn, it commanded the autopilot to prime the localiser guidance. This immediately resulted in the autopilot switching to its localiser capture mode using the simulated GBAS approach guidance Arinc data from the aircraft model. This can be seen in Figure 3.9-3 where, at just after 71600 seconds (1953:20), the actual bank angle no longer tracks the demanded value (there is also a slight increase in the cross-track error at this point). The MFMS also commanded the autopilot to prime its glide slope capture control law and consequently the autopilot transitioned on to the glide slope using the GBAS-derived glide slope deviation data. Figure 3.9-4 shows the altitude profile flown for this test within the STAR, the green line being the demanded altitude from the MFMS. As the aircraft followed the glide slope, the MFMS continued to compute its own estimate of the glide slope deviation value (see Figure 3.9-5). By monitoring the data on the aircraft model screen, it was possible to see that the MFMS-derived deviation value closely matched that computed by the aircraft model, for the majority of the approach the difference was less than 0.005º. The MFMS essentially estimated that the aircraft was within about 1m of the 3º glide slope throughout the approach. On a previous test run, with the GBAS approach guidance output having been disabled, it had been proven that the autopilot would accept the glide slope deviation data from the MFMS and was able to fly the vertical part of the approach using this information.



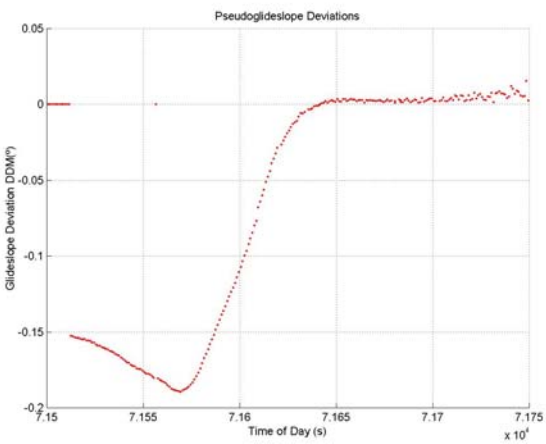


Figure 3.9-4: Altitude Profile within the STAR for Precision Approach Test

Figure 3.9-5: Glide Slope Deviation (in degrees) computed by the MFMS

There was still a problem with the MFMS triggering the descent to 2500ft beyond the planned point and there were also some problems with the trajectory prediction if the approach route had an additional waypoint between DM003 and the runway touchdown position. This was influencing part of the behaviour of the MFMS precision approach algorithm, but the primary components were now working as intended. However, with little time now available at this stage prior to the trials in Rome, it was decided not to continue the development of the precision approach function in favour of concentrating on the ASAS functions and communications applications that were required for the Rome flight trials.

3.10 Software Build E1

Delivered 3rd March 2003
Update E1A-1 6th March 2003
Update E1A-2 12th March 2003
Update E1A-3 17th March 2003
Update E1A-4 21st March 2003 (although not implemented before the Rome trials)

This software build was to form the basis of the version that was to be flown during the trials in Rome towards the end of March. Therefore the majority of the testing was aimed at improving the functionality that would be required for these flight trials. As noted in Chapter 3.9, some testing of the precision approach function was still possible to see if the latest modifications would allow it to be flown at Boscombe Down, but its performance could not quite be guaranteed to be committed to a flight without some further development.

This software build of the MFMS provided the following improvements:

- Improved tracking of the subphase changes by the guidance process;
- Modifications to speed change implementation for merge manoeuvres;
- Updated method for calculating relative along-track distance within profile guidance;
- Corrections to precision approach function;
- Modification to thrust computation to improve predicted descent rate;
- Revisions to a number of HMI issues;
- An updated version of the navigation database for the European region;
- Overlays on the ND of waypoints, navaids and airports now selectable via the soft keys.

Some guidance problems were encountered during the initial test runs with this build when activating a new trajectory that had been predicted for pass-behind manoeuvres. It was identified that a rogue process was being triggered that caused some lateral route information to be over-written. This was corrected and the order in which the various FMU tasks were activated was also revised in order to resolve this issue and allow the testing of the delegated ASAS manoeuvres to continue.

As well as testing the standard merge behind manoeuvre, there was an additional variation that included the specification by ATC of an initial heading for the aircraft. In this case, the instruction from ATC would include not only the identity of the target aircraft, the minimum spacing required and the name of the merge waypoint, but also the heading that the aircraft must initially follow. The MFMS then computes a trajectory that transitions on to this new heading, which is then maintained until the point at which the MFMS has determined that a go-direct to the merge waypoint should be carried out to achieve the necessary spacing. A couple of initial test runs were performed using this function to confirm its method of behaviour in zero-wind and ISA conditions. A modified version of the QNQ1 route had been produced which went direct from waypoint KATE at the end of the SID to FFF and then to waypoint BBB. A simulated target aircraft was created that was on a track to FFF and then continued to BBB. With a heading value entered as 240º, a minimum spacing of 5nm and the merge waypoint set to be FFF, a trajectory was generated with the BAC 1-11 currently on the track between KATE and FFF and in the cruise at FL120. The resultant trajectory turned the aircraft on to the new heading before then turning back towards FFF, the speed demand increasing from 260kts to 277kts CAS during the course of the manoeuvre as well. The speed demand then reduced to 256kts CAS to try and match the speed of the target aircraft, which was approximately 5nm ahead when the BAC 1-11 passed FFF. This was probably closer than it should have been, however, due to the 2nm buffer that the MFMS manoeuvre generator applied to the spacing distance.

Testing of the standard merge manoeuvre was performed using the QNQ1 route that was being used for the flight trials from Boscombe Down. This incorporated two locations along the route where a merge behind manoeuvre could be carried out. The first was when the BAC 1-11 was on the leg from PPP to QQQ and the simulated target aircraft tracking from ZZZ to RRR (the merge waypoint). The second was when the BAC 1-11 was on the leg between waypoints SSS and TTT and the target aircraft was on a track from HHH to ZZZ (the merge waypoint). These two merge manoeuvres occurred after the four pass behind manoeuvres had been carried out earlier along the QNQ1 route. The results with the initial version of this software build showed that there were still some problems with the handling of the additional speed subphases associated with the merge-behind manoeuvre. An additional consequence of this problem was that the success of the prediction of a trajectory for the merge-behind was very sensitive to the value of the spacing distance that was entered via the MCDU.

Waypoint	Track Angle	Ground Speed
MET01	270º	362kts
MET02	309º	356kts
MET03	051º	310kts
MET04	017º	325kts
MET05	090º	306kts
MET06	160º	324kts

Table 3.10-1: Test of Interpretation of Forecast Wind Data

One of the updates that was received for this build version was the application that allowed forecast meteorological data to be used in the trajectory predictions to improve the ground speed determination and consequently the estimated times at each waypoint. This would be important to the success of the revised speed planning for the merge behind manoeuvre. This forecast data was read in by the MFMS from a file, the data being contained in a series of lat./long. grid points, the data at each point consisting of the forecast temperature, wind direction and wind speed at eight different pressure levels. Tests were performed to ensure that the MFMS was interpreting this data correctly by checking the output file containing the predicted trajectory points. The information stored for each trajectory point included the forecast air temperature and wind speed and direction at the 3D position for that point. After resolving a couple of problems with the way the data was being handled by the MFMS, it was possible to confirm that the adjustment to the ground speed was being computed correctly, dependent on the predicted track angle. Table 3.10-1shows the results for the ground speed between a set of waypoints with a constant forecast wind having a direction of

090º True and a speed of 30kts. The zero wind ground speed was of the order of 333kts, although there were some small variations due to minor changes in the True Air Speed value.

The aircraft model programme was also able to use the forecast meteorological files so that both the MFMS and the aircraft simulation could be operated with non-standard weather conditions, making the test runs more representative of the real-world environment. The aircraft model would often be used with a forecast file associated with a different time of day from that used by the MFMS to induce some form of variation in the data. When testing was carried out with this configuration using the QNQ1 trials route, it was noted that the pass behind manoeuvres were not always now successfully predicted, especially when forecasts were used for a day when there were 90 to 100kts of wind being estimated at FL240. The MFMS was successfully computing the lateral adjustment for the pass behind, but the technique of applying time constraints to these manoeuvre waypoints was causing the difficulty. It was originally assumed that, with high wind speeds, the time constraints were not being determined with sufficient allowance for the variations in ground speed that arose for track changes of between 20º and 30º (the typical values associated with these manoeuvres). It was subsequently determined, however, that the use of the forecast meteorological data could have an adverse effect on the air speed conversions between TAS and CAS and consequently influenced the ground speed computation. Although a fix was produced, it was a part of several other modifications forming the E1A-4 update, which arrived too late to be integrated and fully tested at Boscombe Down before the Rome trials.

A modification was made to limit the effect of the time constraints for the pass-behind manoeuvre and this proved successful, tests showing that for each of the four situations encountered on the QNQ1 route, there was no predicted speed change, only the lateral path adjustment. Some additional changes were made to ensure that the CAS rate demand from the MFMS to the autopilot was always within sensible bounds. On a number of occasions, this value had been seen to be very small, causing the autopilot to adjust the aircraft's speed to the new demand very slowly, which could be a problem for the execution of the merge-behind manoeuvre. The tolerance buffer applied to the minimum spacing value for the merge manoeuvre had also been reduced from 2nm to 0.5nm.

Work was also carried out to integrate the CMU software and the associated software components for the FMU that had been developed during specific communications testing at Boscombe Down with the latest FMU software containing the recent modifications to the ASAS functionality. This was completed in time for the first flight to Rome on the 19th March to test the air/ground communications and the suitability of the proposed route in the allocated trials area. Since the set up parameters for the VDL-4 equipment were different for the Rome environment compared to those for Boscombe Down, confirmation that the MFMS would manage to identify the ground stations could only be fully achieved on the flight itself.

Following the flight out to Rome and back on the 19th March, a further update was received to parts of the trajectory prediction and manoeuvre generator functions of the MFMS. Since the priority was now on the trials that were to take place in Rome during the week after, the ground testing with the aircraft model rig was now concentrated on using the planned Rome routes. Chapter 3.11 outlines the processes that took place to develop the scenarios that were to be used for the trials in Rome. During the latter stages of the ground testing of the MFMS functionality at Boscombe Down, parallel testing of the system had already been taking place to verify that the proposed manoeuvres could be accomplished around the Rome route. This testing had led to the requirement to increase the bank angle used in the determination of the ASAS manoeuvres from 20º to 25º in order to ensure that the MFMS could compute a lateral route adjustment within the limited area that would be available.

Using the QNQ5 route that had been flown in Rome, a test run was carried out with the latest software update and using the forecast meteorological data from the 19th March. This route involved two pass-behinds followed by one merge-behind manoeuvre. The manoeuvres were all completed with reasonable success, each manoeuvre being generated first time. The pass-behind manoeuvres were both computed with the minimum spacing distance set to be 6nm, with an additional 0.25nm tolerance being applied by the MFMS. Figure 3.10-1 shows the tracks of the BAC 1-11 (the blue line) and the simulated target aircraft SIM02 (the red line), representing the ATTAS aircraft, during the first pass-behind manoeuvre (the BAC 1-11 was flying north to south, while SIM02 was flying west to east). The two aircraft were predicted to reach the intercept point between their original tracks within 1 second of each other. Therefore the MFMS had to insert a deviation of 9nm in the lateral path of the BAC 1-11 in order to ensure that the required minimum spacing was not compromised. During the manoeuvre, the actual spacing at the closest point of approach was of the order of 6.2nm (see Figure 3.10-2).

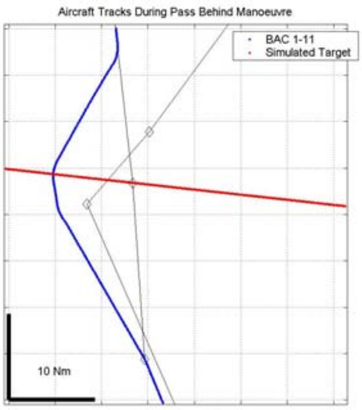


Figure 3.10-1: Tracks of BAC 1-11 (blue) and SIM02 (red) during 1st Pass Behind Manoeuvre

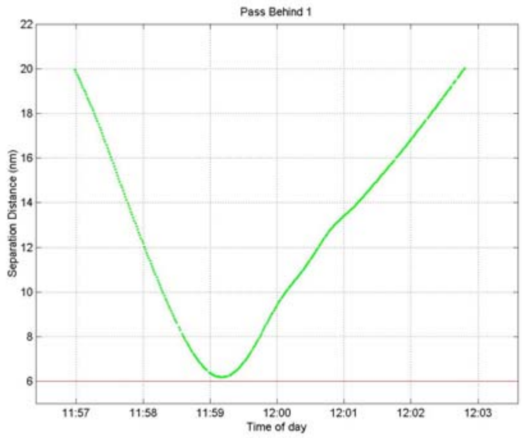
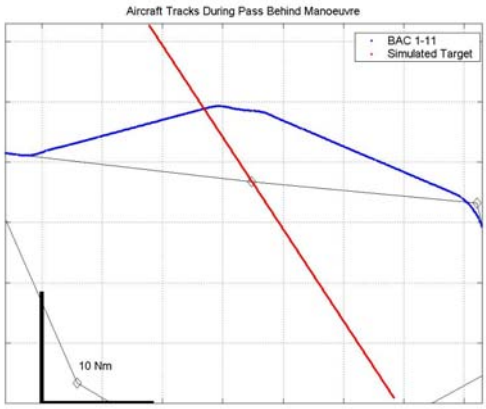


Figure 3.10-2: Spacing of BAC 1-11 from SIM02 during 1st Pass Behind Manoeuvre

For the second pass behind manoeuvre, as can be seen in Figure 3.10-3, the BAC 1-11 was now on an easterly track while the target aircraft (still SIM02) was heading in a more south-easterly direction, giving a shallower intercept of about 50º in their respective tracks. With the target aircraft now predicted to be 30 seconds ahead of the BAC 1-11 at the intercept point, the deviation in the lateral path of the BAC 1-11 determined for this pass-behind, was only 6.4nm on this occasion. The resultant spacing at the closest point of approach was again 6.2nm (see Figure 3.10-4).



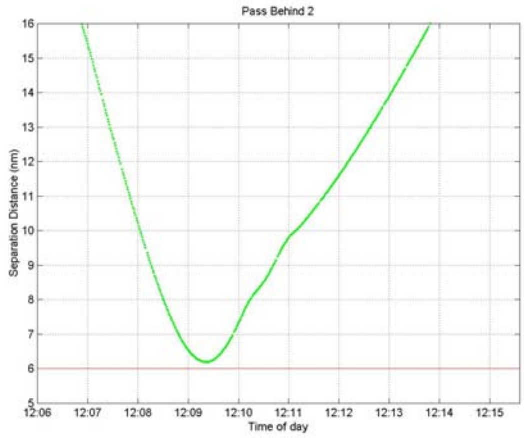


Figure 3.10-3: Tracks of BAC 1-11 (blue) and SIM02 (red) during 2nd Pass Behind Manoeuvre

Figure 3.10-4: Spacing of BAC 1-11 from SIM02 during 2nd Pass Behind Manoeuvre

During the manoeuvres themselves the actual spacing encountered at the CPA was of the order of 6.5nm. For the merge behind, a spacing distance of 20nm was used (as noted earlier, the MFMS applied an extra 0.5nm buffer to this value to allow for inaccuracies in the prediction). An updated speed demand of 279kts CAS was determined by the MFMS to achieve this spacing and by the time the BAC 1-11 was at the merge waypoint MMP, its spacing behind the simulated target aircraft was 20.6nm. With this test showing a more consistent performance, the system was then flown on the BAC 1-11 later that day (20th March) to confirm this behaviour using the Boscombe trials route QNQ1. This was the last testing that could be carried out before the Rome trials since all the components then had to be packaged up ready for transportation on the BAC 1-11 to Rome on the 24th March.

3.11 Development of Rome Trials Scenario

Co-ordinates of the area to carry out the trials in were given by Rome ATC. Working from the SIDs from Ciampino gave a likely range of entry points into the trials area.

Using the CAS of 210 knots for the ATTAS and 250 knots for the BAC 1-11, a TAS was calculated for each aircraft using the approximation calculated from the equation given in 3.11 - 1:

$$TAS \approx \frac{81}{81-h} \times CAS \qquad \textit{3.11 - 1}$$

where h is height in 1000's of feet, and for these trials was 21.

Other than ensuring that the two aircraft maintained the required minimum separation throughout the flight, the following constraints were also imposed:

- to give enough room between waypoints for turns of minimum five mile radius, turning before each waypoint.
- to try to make all turns no greater than 90°, (not always possible).
- to either keep the route away from the boundary to the trials area or to avoid requiring a sharp turn to stay within the boundary.

- for each pass-behind manoeuvre, to make the ATTAS approach the path of the BAC 1-11 at as large an angle as possible.
- to give sufficient room/time for each pass behind (for the BAC 1-11 to calculate the manoeuvre once stable after making a turn, and to be able to generate the track for the manoeuvre with a maximum bank of 25°).
- to give as long a run as possible, given the size of the area, for the merge-behind – essentially to make the merge leg start at one end of the area and finish as far away as possible, keeping cognisant of the other constraints in this list.
- to give approximately coincident conflict points for the pass-behind manoeuvres.
- to make the BAC 1-11 be between 10 and 25 nautical miles behind the ATTAS at the start of the merge manoeuvre.
- to make the leg immediately after the merge at least 20 nautical miles long.
- to make the turn after the merge manoeuvre less than 30°.
- to ensure that the total airborne time for the ATTAS is not longer than 1 hour 50 minutes.
- to use ESINO, TORLI and OST for both aircraft to leave the trials area and enter the STAR.

Additionally, where possible, contingency was put into the route so that minor adjustments could be made to facilitate either increasing or decreasing the spacing between the aircraft at the crucial waypoints. That is, the waypoints were arranged such that the legs could be made either longer or shorter yet not significantly affect the manoeuvre legs.

Where possible (and it was possible at each instance), after a pass-behind manoeuvre where the BAC 1-11 resumes to the next waypoint, the turn at this waypoint should be in the aircraft's favour, ie the turn should be to the right if the manoeuvre sent the aircraft left of its original path and vice versa. As well as putting the BAC 1-11 through less extreme manoeuvres, this also helped to fit the route into the area more easily.

Lat/long coordinates of the vertices of the drawn routes were read off the charts and entered into the MA-AFAS FMS as route waypoints.

A number of simulation runs were carried out to verify that the routes could be generated and to refine the routes for improved timing between the aircraft.

Around this time, co-ordinates for a new trials area were supplied (see Figure 3.11-1), the newer area being smaller than the original.

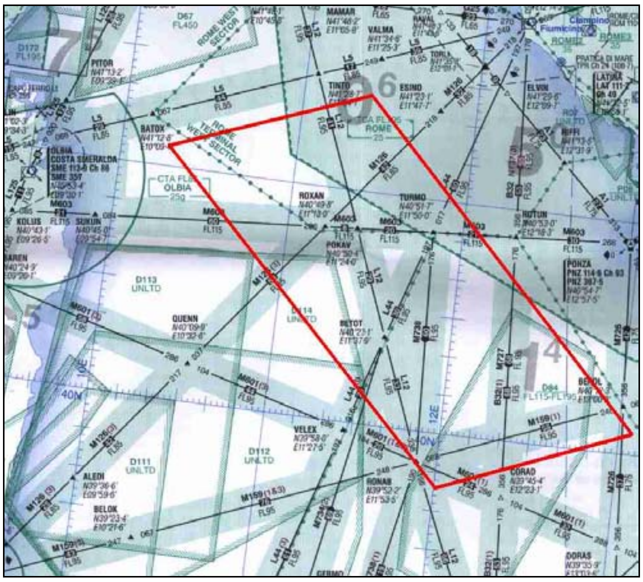


Figure 3.11-1: Second Trials Area

Further co-ordinates for a similar area to that above were supplied. The newest area avoided some danger areas, so was smaller again (see Figure 3.11-2). This area was considered to be the most likely one to be made available during the Rome flight trials.

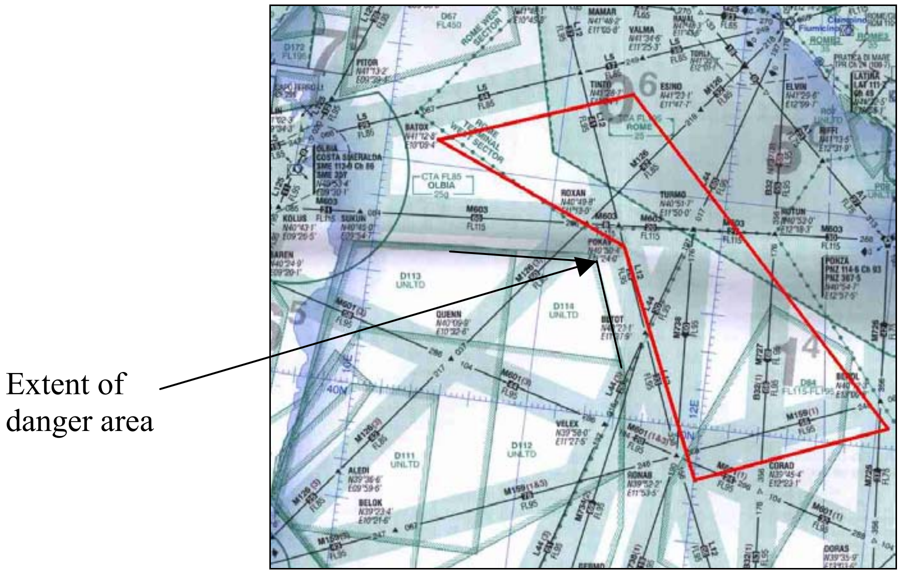


Figure 3.11-2: Allocated Area Used for Flight Trials

Calculations and drawings had to be started again to fit new routes into the new areas using the same constraints already listed. Unfortunately, in order to fit three pass-behind manoeuvres in the smallest area, the only solution found was one where the ATTAS had to take-off about one minute after the BAC 1-11. Therefore the number of pass-behind manoeuvres in each flight was reduced to two. They could be fitted into the smallest area with a more sensible interval between take-off times.

A route was produced for the larger of the new areas, even though it was considered unlikely that it would actually be made available during the flight trials.

In Figure 3.11-3 and Figure 3.11-4 the waypoints are labelled in numerical order with prefix A for the ATTAS, B for the BAC 1-11, and P for the pass-behind manoeuvre conflict points. MMP and MMP2 are the merge manoeuvre points (one in each route) and EP is the end point for the merge manoeuvre in Figure 3.11-4 only.

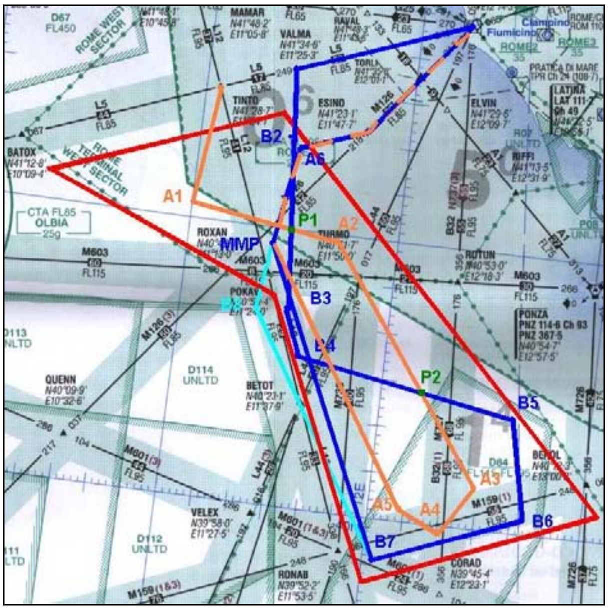


Figure 3.11-3: Route Flown

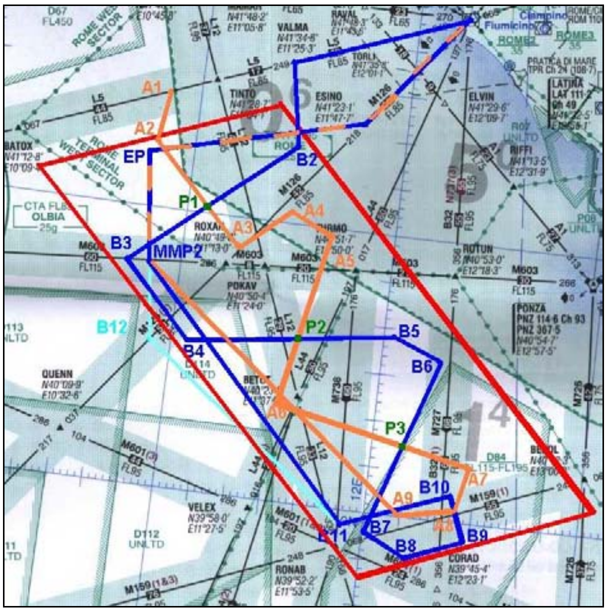


Figure 3.11-4: Alternative Route

BAC 1-11 route
ATTAS route
Merge manoeuvre legs never flown
Both aircraft after merge
Cleared area boundary

Co-ordinates of the waypoints in the new routes were entered into the MA-AFAS FMS. The time to start the target aircraft in simulation was calculated. This time was refined at the first attempt to run the simulation.

The route was flown in simulation using the FMS to control the target aircraft. The times for the target aircraft to reach its various waypoints were noted for checking and possible refining later. These times were approximate not least because the target aircraft in simulation turns instantaneously at each waypoint and for most simulation runs no effect from wind was used.

The routes were altered slightly after running in simulation so that timings were better or less critical, and the BAC 1-11 reached the merge manoeuvre at the correct time.

The time at which to start the target aircraft (which was started instantaneously in the cruise) and, by extrapolation, an approximate time for the interval between take-offs of the BAC 1-11 and the ATTAS was calculated.

The route to be flown by the ATTAS was sent to DLR to fly in simulation to verify that the aircraft could fly the given route comfortably and to confirm or refine timings given by simulation at Boscombe.

The co-ordinates of the flown routes are shown in Table 3.11-1 and Table 3.11-2.

LUNAK	N41° 42' 06.00"	E011° 52' 12.00"
VALMA	N41° 34' 36.00"	E011° 25' 18.00"
B2	N41° 20' 00.00"	E011° 26' 00.00"
P1	N41° 00' 30.00"	E011° 29' 00.00"
B3	N40° 40' 00.00"	E011° 31' 00.00"
B4	N40° 31' 00.00"	E011° 36' 00.00"
P2	N40° 28' 00.00"	E012° 10' 30.00"
B5	N40° 26' 00.00"	E012° 37' 00.00"
B6	N40° 02' 30.00"	E012° 43' 00.00"
B7	N39° 51' 00.00"	E012° 02' 30.00"
B8	N40° 42' 00.00"	E011° 21' 30.00"
MMP	N40° 57' 00.00"	E011° 24' 30.00"
A6	N41° 17' 30.00"	E011° 28' 30.00"
ESINO	N41° 23' 06.00"	E011° 47' 42.00"
TORLI	N41° 35' 42.00"	E012° 01' 06.00"
OST	N41° 48' 12.00"	E012° 14' 18.00"

Table 3.11-1: BAC 1-11 Route Waypoint Co-ordinates

TINTO	N41° 28' 42.00"	E011° 04' 06.00"
A1	N41° 02' 30.00"	E011° 00' 00.00"
P1	N41° 00' 30.00"	E011° 29' 00.00"
A2	N40° 59' 00.00"	E011° 44' 00.00"
P2	N40° 28' 00.00"	E012° 10' 30.00"
A3	N40° 08' 30.00"	E012° 27' 30.00"
A4	N39° 59' 00.00"	E012° 21' 30.00"
A5	N40° 02' 30.00"	E012° 08' 00.00"
MMP	N40° 57' 00.00"	E011° 24' 30.00"
A6	N41° 17' 30.00"	E011° 28' 30.00"
ESINO	N41° 23' 06.00"	E011° 47' 42.00"
TORLI	N41° 35' 48.00"	E012° 01' 06.00"
OST	N41° 48' 12.00"	E012° 14' 18.00"

Table 3.11-2: ATTAS Route Waypoint Co-ordinates

3.12 Data Link Communications Testing

The lab at Boscombe Down was used for communication testing and integration of the various communications related systems.

3.12.1 Routers

Various configurations of the communication routers were tested/integrated:
- Ethernet based;
- Transponder Based (using attenuator cable and free space propagation);
- Single router (air/ground router local to lab);
- Multiple routers (air/ground router in Boscombe connected to ground/ground router in EEC RC).

During this time a VxWorks air router crash problem was investigated and resolved.

3.12.2 Context Management (CM)

Testing of the CM functionality was carried out with the MCDU. This used test software to receive the CM logon request and provide the CM logon response. This testing proved to be successful.

Testing was also performed to achieve a CM logon with the EEC RC, using an ISDN link to the EEC RC. A CM logon request was initiated from the MCDU, tracked through the FMU CM functionality, the CMU air router, the air/ground router, the ground/ground router and into the EEC

RC CM application. It was found, however, that the CM logon request was then discarded by the EEC RC CM application. Time for testing with the EEC RC ran out before a resolution to this problem could be found.

3.12.3 Controller-Pilot Data Link Communications (CPDLC)

Testing of the CPDLC functionality was also performed with the MCDU. This used the IHTP CSV injection facility to send CPDLC service primitives and CPDLC messages. Testing was partially successful. The CPDLC protocol was successfully handled by the avionics and messages were received by the avionics, however, the immaturity of the MCDU CPDLC functionality meant that messages were not always correctly displayed and that the correct responses were not always sent by the MCDU.

This testing was performed with transponders connected both via attenuator cable and using VHF free space propagation (short range only).

3.12.4 ADS-B

Testing of the ADS-B functionality was aimed at demonstrating the display of target traffic on the Navigation Display (ND).

This involved testing of the transponders with the Broadcast Manager, Surveillance Data Base (SDB) and Navigation Display to display the received ADS-B reports as target aircraft on the ND. This was performed successfully for stationary ground based transponders and during one flight of the BAC1-11, when data was received from the aircraft by the ground test equipment in the laboratory (the BAC1-11 was successfully seen on the ND as it approached Boscombe Down for landing).

Testing of the ADS-B functionality to send aircraft position reports and intent information from the avionics rig via the VDL4 transponder was carried out. This function did not work and caused the mobile transponder to lock up and stop transmitting. No resolution to this problem was found. This meant that for the flight trials, the ADS-B data transmitted by the transponders used the position and velocity data determined by the GPS within the VDL4 transponder rather than that from the MFMS itself.

3.12.5 Traffic Information Service – Broadcast (TIS-B)

Testing of the TIS-B functionality considered the display of target traffic on the ND, which had been received from transmissions from the ATC ground station.

The EEC RC was used to send TIS-B tracks via the ISDN link to BAGS. The received ASTERIX data stream was then converted into a VDL4 FAB report conforming to the NUP TIS-B format that was “transmitted” to the avionics via the air/ground router, transponders, air router and broadcast manager. The SDB then decoded the TIS-B and stored the target aircraft for display on the ND. During this time AMS provided telephone and on-site BAGS support.

Data sent by the EEC RC was being received by the SDB, however, no target aircraft were being displayed on the ND. Time for testing with the EEC RC ran out before a resolution to this problem could be found. There were a number of problems relating to this application:

- with the data sent from EEC RC;
- with decoding/encoding of data within BAGS;
- with decoding of data within the SDB.

4 EEC Tests

MA-AFAS has used the ATM and ground requirements, ground infrastructure and operational scenario, as defined and reviewed by users (such as airlines and ATS providers) in WP1 – Operational Concept, as a basis. This scenario has been refined, with the support of EEC controller team, in order to fit to the simulation area and to prepare Boscombe and Rome trials. The retrofit avionics solution has been designed and developed to meet this baseline (under WP2 – Avionics Package) and demonstrated within representative future ATM environments (under WP3 – Validation). The following capabilities have been specifically addressed at the EEC:

- Validation of ADS-B (using VDL Mode 4) with airborne display of traffic (CDTI) and separation assurance algorithms
- ASAS functions test

4.1 Ground System Preparation

4.1.1 Trials Infrastructure

The following two diagrams (Figure 4.1-1 and) give an overview of the trials infrastructure and the ESCAPE high-level functions in relation to the MA-AFAS live trials.

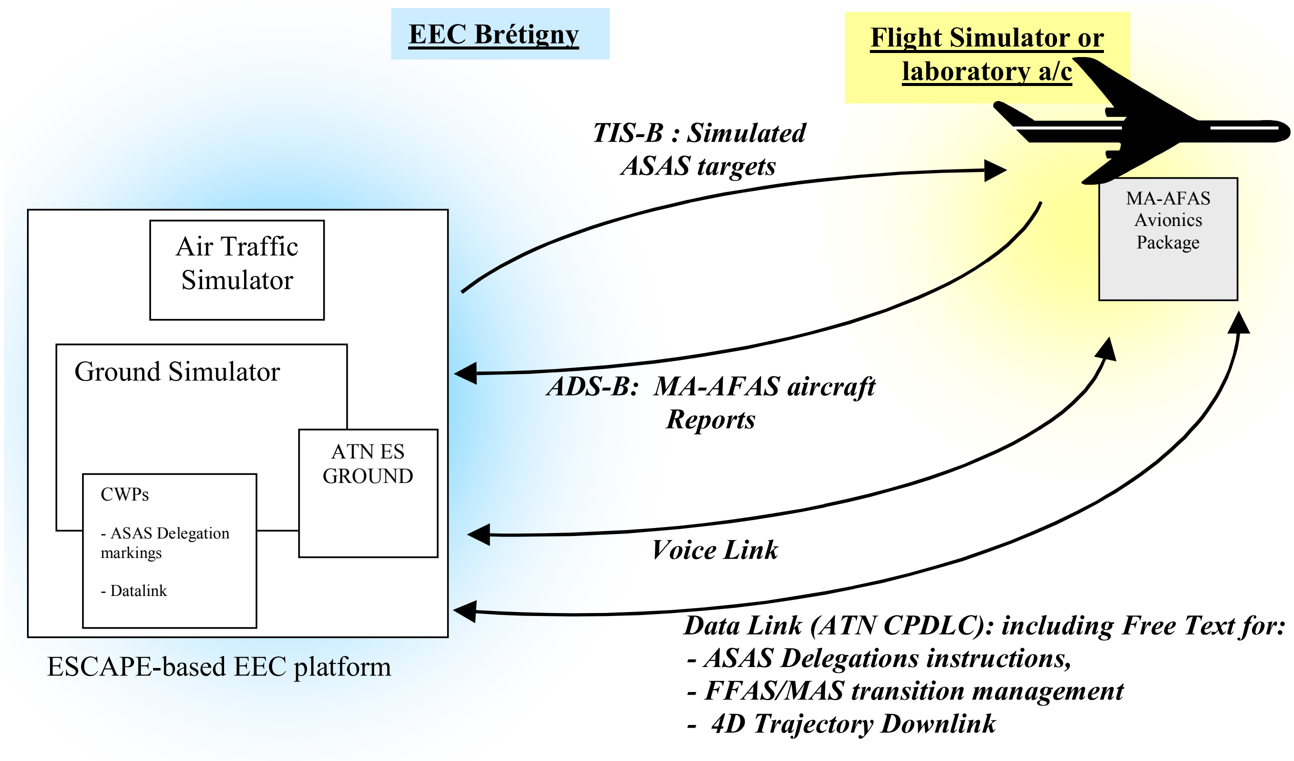
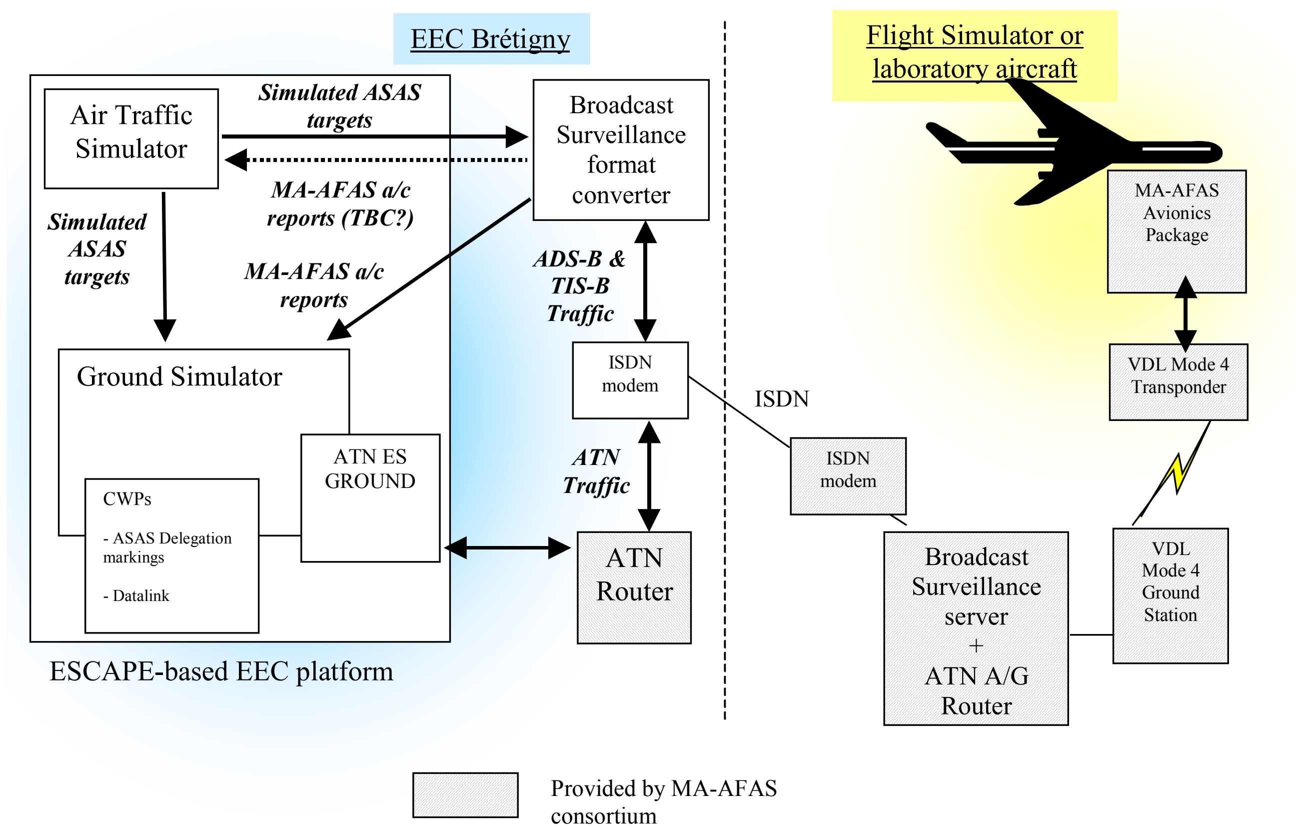


Figure 4.1-1: High Level view of air-ground communications



EEC Brétigny
Flight Simulator or laboratory aircraft
Air Traffic Simulator
Simulated ASAS targets
MA-AFAS a/c reports (TBC?)
Broadcast Surveillance format converter
Simulated ASAS targets
MA-AFAS a/c reports
ADS-B & TIS-B Traffic
MA-AFAS Avionics Package
Ground Simulator
ISDN modem
ISDN
VDL Mode 4 Transponder
ATN ES GROUND
ATN Traffic
ISDN modem
CWPs
- ASAS Delegation markings
- Datalink
ATN Router
Broadcast Surveillance server + ATN A/G Router
VDL Mode 4 Ground Station
ESCAPE-based EEC platform
Provided by MA-AFAS consortium

Figure 4.1-2: Overview of live trials chain and ESCAPE functions

In support of these high-level testing objectives, the MA-AFAS ground platform has provided the following functions:

- **Simulation of Air Traffic** for the purpose of providing the live aircraft (or flight simulators) with "virtual" ASAS targets in order to enable the first stage of evaluation of the MA-AFAS avionics, including such features as basic data link services, and ASAS functionality.
- Access, or link to **live Broadcast Surveillance services** in order to convey surveillance data from/to the live aircraft (or ground simulators). The MA-AFAS platform has been built on the experience gained from:
  - previous data link projects such as LINK2000+ and DOVE, in order to re-use data-link services implementations in ESCAPE;
  - ASAS-related simulations (i.e. CO-SPACE project), including procedures and phraseology aspects, and delegation markings on the CWP;
- **Voice communications** with the live aircraft (or ground simulators) (primary communication means or D/L backup);
- **Data-link communications** with the live aircraft (or ground simulators), as a primary communication means or complement to Voice communications. Additionally, MA-AFAS data link requirements for live traffic have been fulfilled through the use of a new ATN stack within ESCAPE/EAT, known as IDLS;
- Specific **CWP HMI features** including data link services implementations and delegation markings and display of live aircraft or simulated aircraft position/ground vector on CWP.
- Other Ground functions and various additional requirements.

4.1.2 Platform configuration

Figure 4.1-3 shows the ESCAPE platform configuration used for the MA-AFAS project:

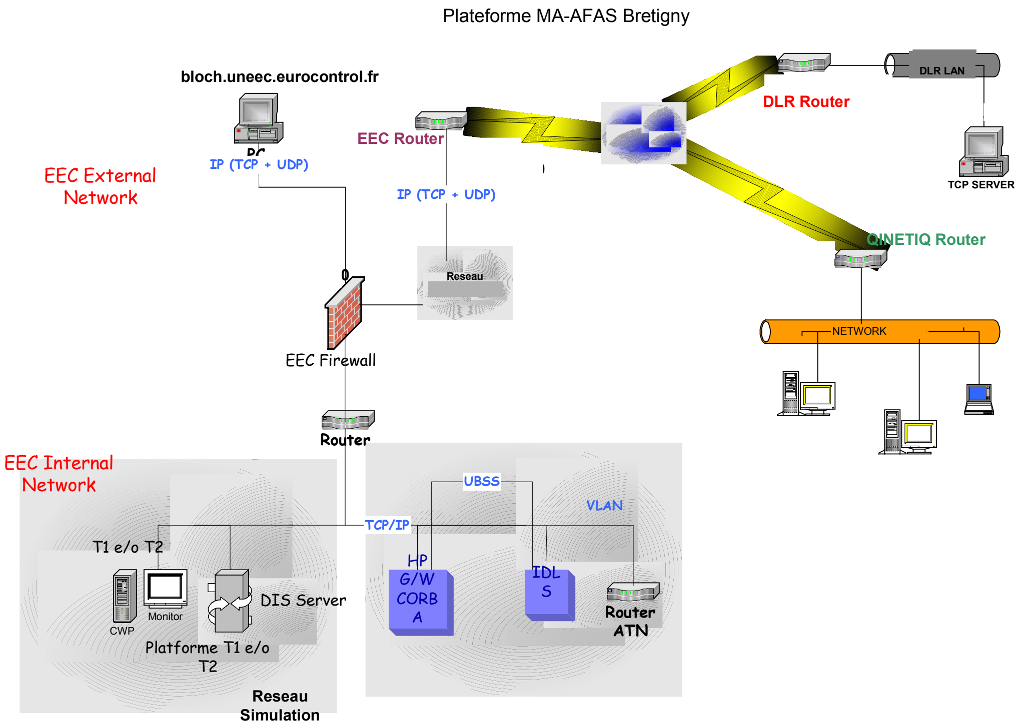


Figure 4.1-3: ESCAPE Configuration for MA-AFAS

4.2 Communications Tests

4.2.1 Communication Tests Results

As described in chapter 4.1, a comprehensive communications and surveillance infrastructure was set up, which allowed live MA-AFAS aircraft to be integrated into traffic simulated on a Eurocontrol Experimental Centre platform. After a step-by-step integration process, the most significant milestones that were reached included:

- the visualisation of the position (and trajectory) of the QinetiQ BAC 1-11 on the EEC's controller working positions. Thanks to the received ADS-B reports, the aircraft was displayed with surrounding simulated "target" traffic, while performing ground testing and trials flights at Boscombe Down.
- simultaneously, the reception, by the MFMS, of the simulated traffic TIS-B parameters sent from ESCAPE.

On the communication side, the end-to-end connection over the ATN link (based on a VDL mode 4 sub-network) was successfully tested. Unfortunately, the extended CPDLC capabilities could not be demonstrated on the link to the EEC ground installation, mostly due to a lack of time.

4.2.2 ASAS Tests Results

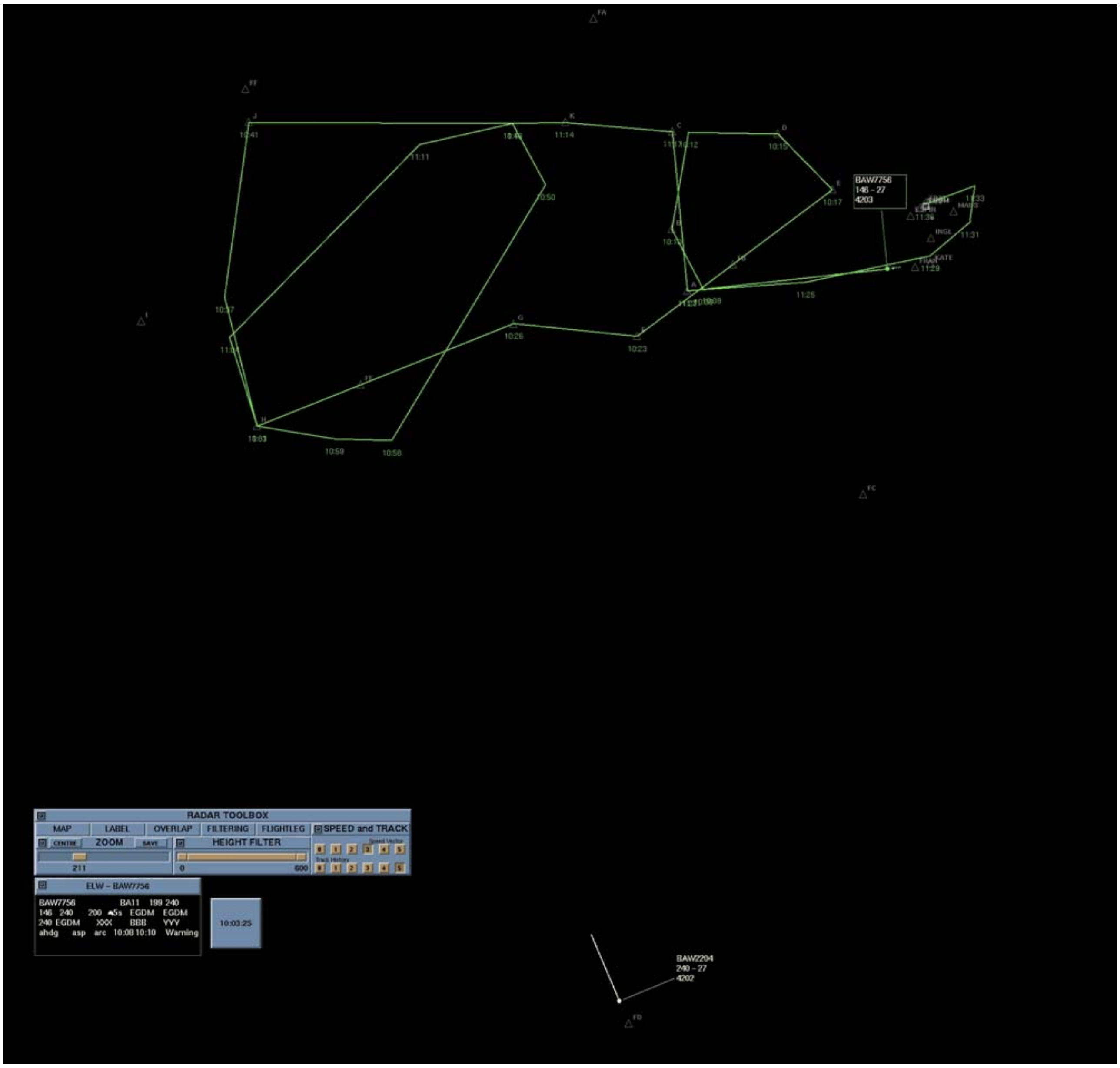


Figure 4.2-1: Screen-shot of CWP during the Tests with the BAC 1-11

In Figure 4.2-1, you can see the trajectory of the BAC 1-11 during the tests.

In Figure 4.2-2, the BAC 1-11 (BAW7756) was flying from waypoint G toward H. In order to avoid a conflict with the other aircraft (BAW2804) at FE, BAW7756 turns left to pass behind.

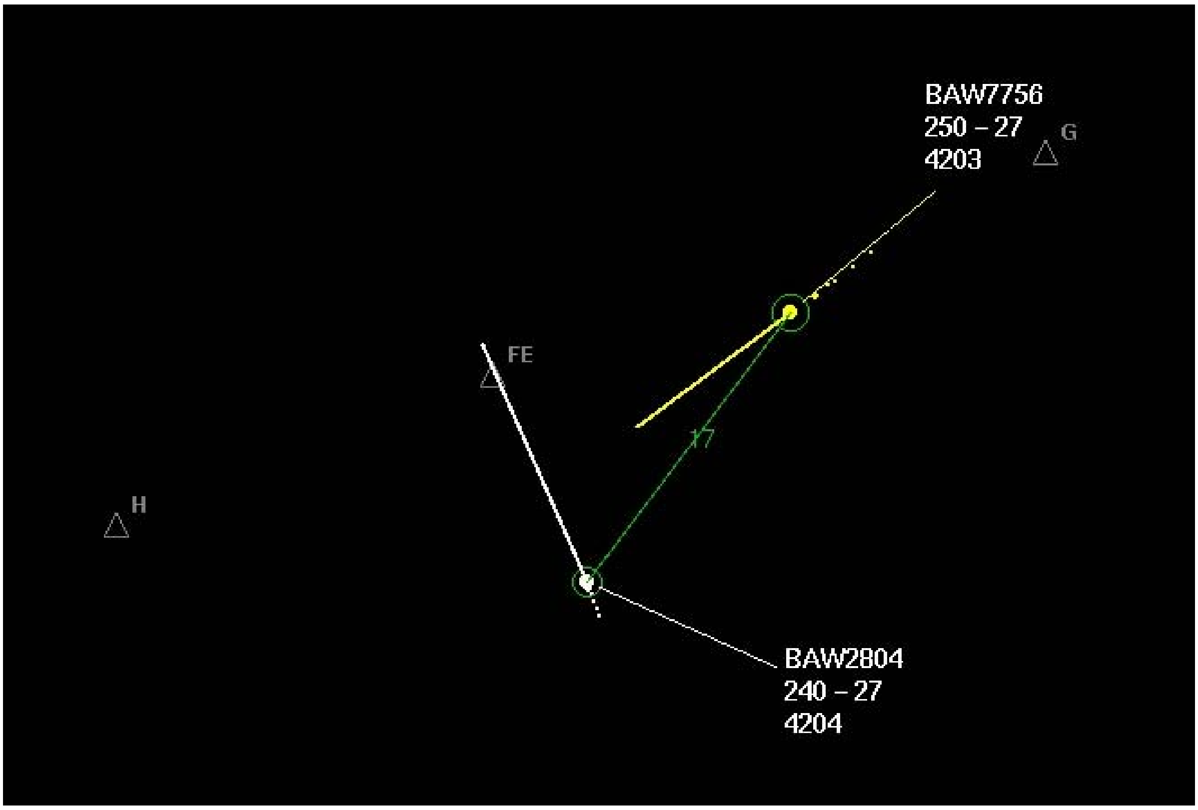


Figure 4.2-2: Execution of a Pass Behind Manoeuvre

In Figure 4.2-3, the closest distance between the two aircraft has been reached, and the BAC 1-11 (BAW7756) is turning right heading toward H.

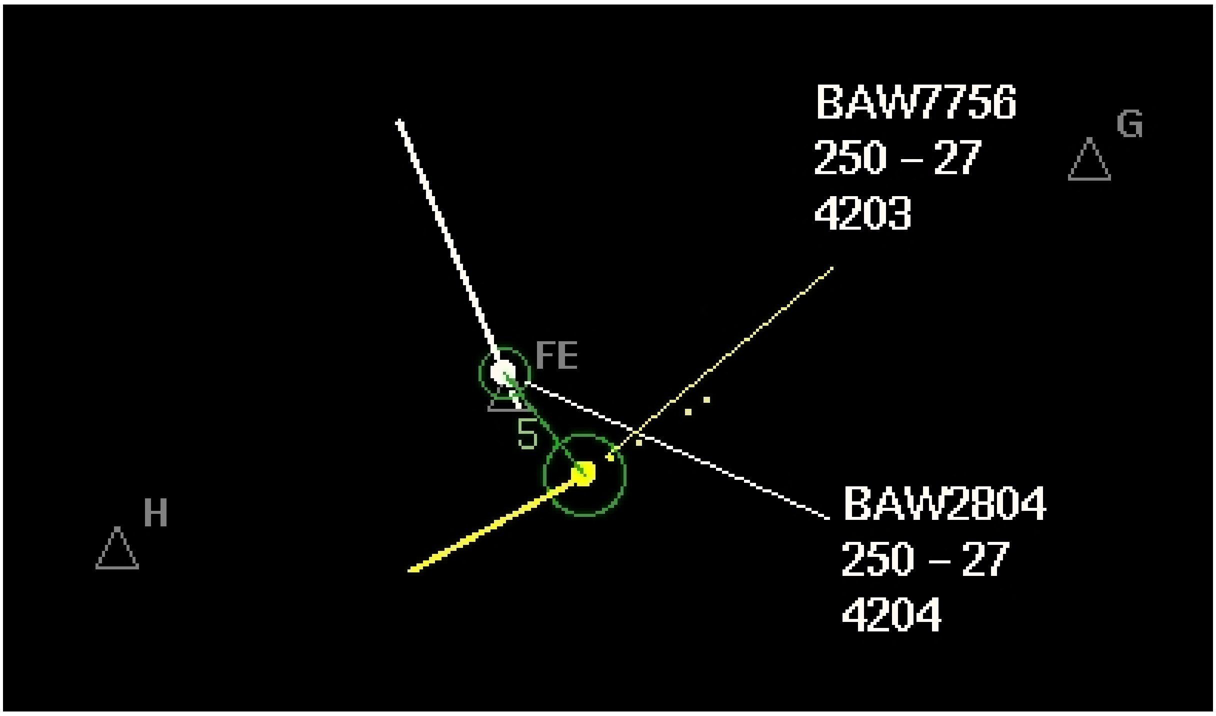


Figure 4.2-3: Closest Point of Approach During Pass Behind

5 DLR Tests

The following sections describe the ground testing that was performed at the DLR facility at Braunschweig, Germany, in preparation to the taxi management and flight testing of the MFMS onboard DLR's ATTAS aircraft that was to take place in May 2003. This continued the development the MFMS functionality after the trials at QinetiQ Boscombe Down and at Rome, the ground testing at DLR being supported by personnel from BAE Systems.

5.1 Braunschweig

5.1.1 Preparation Week 1 – week beginning 28th April 2003

The latest release of the software (E2) was to be used during the run-up to the taxi and flight trials. This software release was continually updated during the preparation to resolve any problems that were found and to add new functionality.

The preparation for the flight trials to be performed at Braunschweig started with the flight trials route preparation. The route consisted of the following waypoints:

POVEL	N52°07'42.00"	E010°49'40.00"
MAG	N51°59'41.96"	E011°47'39.50"
BUROK	N52°05'04.00"	E012°23'51.00"
ESIKA	N52°07'26.00"	E012°40'17.00"
MOSEX	N51°55'09.00"	E012°58'15.00"
BOLBO	N51°47'41.00"	E013°09'04.00"
OLBIK	N51°39'48.00"	E013°20'30.00"
TORVU	N51°35'09.00"	E013°04'37.00"
TADUV	N51°25'48.00"	E012°32'53.00"
ABVIG	N51°24'53.00"	E011°58'10.00"
GALMA	N51°23'53.00"	E011°27'04.00"
BIRKA	N51°22'46.00"	E010°55'54.00"
LARET	N51°50'04.00"	E010°52'10.00"

Table 5.1-1: Braunschweig Flight Trial Route Co-ordinates

The SID, STAR and Approach details were dependent on which runway at Braunschweig was to be used for takeoff/landing:

	RW26	*RW08*
SID	POVE3W	POVE3U
STAR	LARE3R	LARE3H
Approach	P26	P08

Table 5.1-2: Braunschweig SID/STAR/Approach Details

A problem was found when the approach constraint points were added. All of the go-around waypoints were selected from the Approach and subsequently displayed on the MCDU LEGS page. This meant that trajectories were not able to be successfully generated. The first solution was to simply delete the additional constraint points from the LEGS page and then a successful trajectory could be generated. Subsequently a supplemental approach was created which contained only the waypoints that were required.

For the initial test an altitude constraint was added to the last en-route waypoint (BIRKA) to delay the descent. All of the altitude constraints within the SID and STAR were also removed. This was later removed for the later testing.

The first few tests performed were simply to fly the route with the simulator to verify that the route could be flown with no problems and these tests were successful.

Next, time was spent planning which manoeuvres to perform during the flights. The list of available manoeuvres was:

Pass Behind
Merge Behind
Remain Behind
Change Spacing

The initial plans were:

a) perform a Pass Behind between MAG and ESIKA
b) perform a Remain Behind between ESIKA and ABVIG, including Change Spacing
c) perform a Merge Behind at ESIKA
d) perform a Merge Behind at OLBIK

Note – not all manoeuvres were planned for a single flight

The dummy surveillance database was to supply the target aircraft to be used for these manoeuvres and time was spent getting the simulated target aircraft into the right areas to perform the manoeuvres.

A number of tests were performed with the Pass Behind and these were all successful.

A number of merges were also attempted but the tests met with very little success. The system tended to crash during the merge trajectory generation, mostly before a trajectory was displayed on the Nav Display.

Note that at this stage the simulator was used but the wind was turned off.

5.1.2 Preparation Week 2 - week beginning 6th May 2003

As the merge manoeuvre was not very successful, time was spent testing the Remain Behind functionality.

Initially, there was a problem when starting the remain in that the trajectory generator was sent the command whereas the message should have been sent to the aircraft guidance. This problem was solved as there was a mismatch between the software and the MCDU menu's file.

When the remain behind was first started the behaviour was as expected, i.e. if the aircraft were too close the speed demand was reduced, if the aircraft were too far apart the speed demand was increased. During the remain behind, about 10/15 minutes after it has been started, the CAS demand of the ownship drops by about 30 knots causing the spacing to fail.

New software was received that attempted to solve the problems that had been experienced with the merge behind manoeuvre. This was tested but still there were problems with the merge so testing ceased on the merge for the time being.

All of the testing up till now had been performed taking off from RW26. Some tests were performed to ensure that taking off from RW08 was OK, these tests were successful.

The current weather forecast was loaded on to the simulator to make the testing more realistic. Tests were performed with pass behind's, remain behind's and merge behind's with similar results, i.e. the pass behind worked very well but the problems experienced with remain and merge still existed.

5.1.3 Preparation Week 3 - week beginning 12th May 2003

Testing continued on the simulator during the week that the taxi trials were being performed.

A change to the trajectory generator that improved the merge behind performance was tested. These results were successful, the merge behind performance was greatly improved with no system crashes witnessed. The change involved reducing the complexity of the merge point calculation.

There was a problem identified within the dummy surveillance database with the ground speed calculation of the target aircraft – this had arisen because the system was now affected by wind. Whenever a target aircraft entered a turn the ground speeds would greatly increase and as the spacing control was controlling the speed demand, the ownship speed would increase to match. Once the target aircraft had completed the turn the ground speed would revert to it's expected value and the ownship speed demand would drop to match it. This had the problem that the spacing between the two aircraft would reduce because the ownship speed had increased for a short while. This problem was resolved within the dummy surveillance database to better take into account the current wind conditions. Once this change had been made the system performance was improved.

A further problem was identified within the spacing functionality when the reported spacing between the two aircraft would suddenly increase to tens of miles more than the actual distance. This problem was as a result of the spacing software "losing" track of the target aircraft on the active trajectory. The solution, for the flight trials, was to always use a lateral spacing calculation and not an "along-track" spacing calculation. This update also solved the problem with the CAS demand suddenly dropping.

At the end of the week the following functions had been tested and were ready to be utilised during the flight trials:

Pass Behind
Remain Behind
Merge Behind
Change Spacing

During the flight trials the Merge Behind with Initial Heading was expected to be made available.

6 AMS Tests

This chapter describes the preparatory tests, necessary to check the MA-AFAS functionality in the laboratory, before the actual trials flight in the Rome environment.

6.1 Introduction

The test activities in the Rome environment had been split into different stages:

The first stage had been necessary to check the integration and interoperability between the MEDUP system and the MA-AFAS equipment (both systems being located in AMS facilities).

After the verification of the correct interoperability between the MEDUP ground system and the MA-AFAS equipment, the test activity was planned to move into the ENAV CNS/ATM Experimental Centre, where a ground ATM system working in shadow mode had been set up.

The aim of the second stage was to guarantee that, before the flight trials, the MA-AFAS system in the ENAV experimental centre should operate correctly with the MEDUP ground stations located in the ACC building.

6.1.1 System Architecture

This chapter contains the description of the System Architecture that was implemented during the Rome flight test.
The MA-AFAS System is made up of the following components:

- ATM Shadow system (ATMS)
- MEDUP ATM Communication Gateway (ACG)
- MEDUP VDL Mode 4 Ground Station (MGS) located in the Ciampino ACC building
- MA-AFAS Equipment.

Figure 6.1-1 shows the final system architecture that was implemented during the trials week.

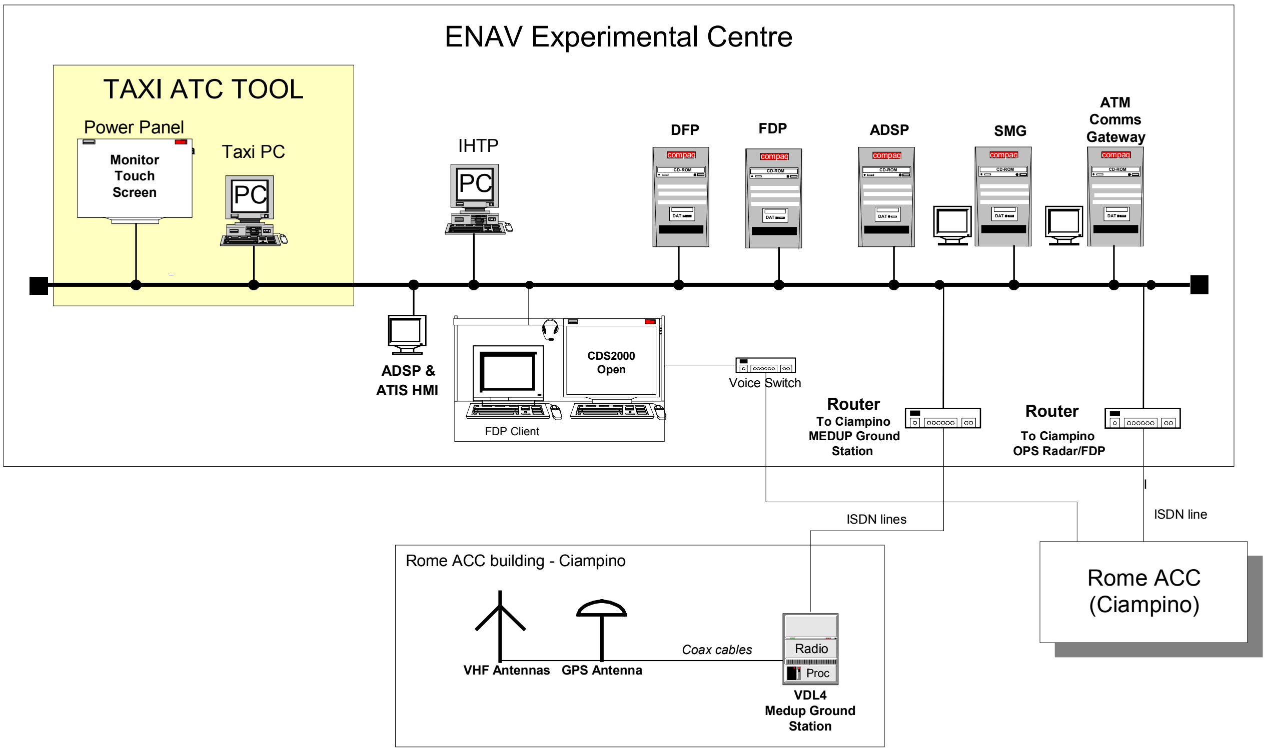


Figure 6.1-1: MA-AFAS System Architecture

ATM Shadow System ATMS
The ATMS includes the following components:

- Surveillance Data Processor (SDP)
- Flight Data Processor (FDP)
- ADS Processor (ADSP)
- Controller Working Position (CWP)
- Shadow Mode Gateway (SMG)

ATM Communication Gateway
The ATM Communication Gateway is in charge of communication management. It provides access to the VDL Mode 4 network through a router connected to the Ground Station located in Ciampino.

MEDUP Ground Station
The MEDUP Ground Station includes a VDL4 base station transponder and the host processor for the ADSB Router software. The MGS guarantees VHF coverage and provision of ADS-B, TIS-B, and FIS-B. The Ground Station also provides an interface to the Air/Ground ATN Router to support the exchange of point-to-point messages through the VDL4 transponder.

MA-AFAS Equipment

- In House test platform (IHTP)
- Taxi ATC Tool (TAT)

The IHTP connection to the TAT would allow Taxi Clearances to be exchanged between the MA-AFAS controller in the ENAV Experimental Centre and the pilot onboard the MA-AFAS aircraft.

6.2 Ground System Preparation

This chapter describes the Experimental System that was necessary to support the communication tests.

The Experimental Ground System was set up in the AMS facility, utilising a VDL4 GS, a VDL4 AS, the Avionics Rack (FMU/CMU) and other ground systems that were connected to simulate the overall system, which was to be installed in the ENAV Experimental Centre and integrated with the MEDUP network.

6.2.1 AMS Test Bed

This chapter describes the MA-AFAS experimental system that was implemented within the AMS facility in Rome. This system was configured to utilise the MEDUP network.

The test bed that was used for the verification tests was composed of the MEDUP system to which the MA-AFAS avionics equipment had been integrated.

The sub-systems that had been added to the MEDUP ground system in the AMS network are shown in Table 6.2-1:

Sub system	Type	Provided by
Ground Segment		
IHTP	PC	BAE SYSTEMS
Taxi Tool	PC	BAE SYSTEMS
Airborne Segment		
Traffic Simulator	PC	BAE SYSTEMS
IHTP (Airborne Simulator)	PC	BAE SYSTEMS
Avionics Rack (FMU/CMU)	PC	BAE SYSTEMS
NAV Display	VGA	BAE SYSTEMS
VDL M4 Airborne Station	Airborne Transponder	BAE SYSTEMS

Table 6.2-1: MA-AFAS Air/Ground Equipment

The MA-AFAS Avionics Rack (FMU/CMU) was linked with the IHTP platform and a real airborne VDL4 transponder was attached to the CMU. Meanwhile the TAT (Taxi ATC Tool) had been connected to the IHTP ATN ES in order to provide the capability to exchange CPDLC messages.

Figure 6.2-1 contains the block diagram of the MA-AFAS system in the AMS Facility.

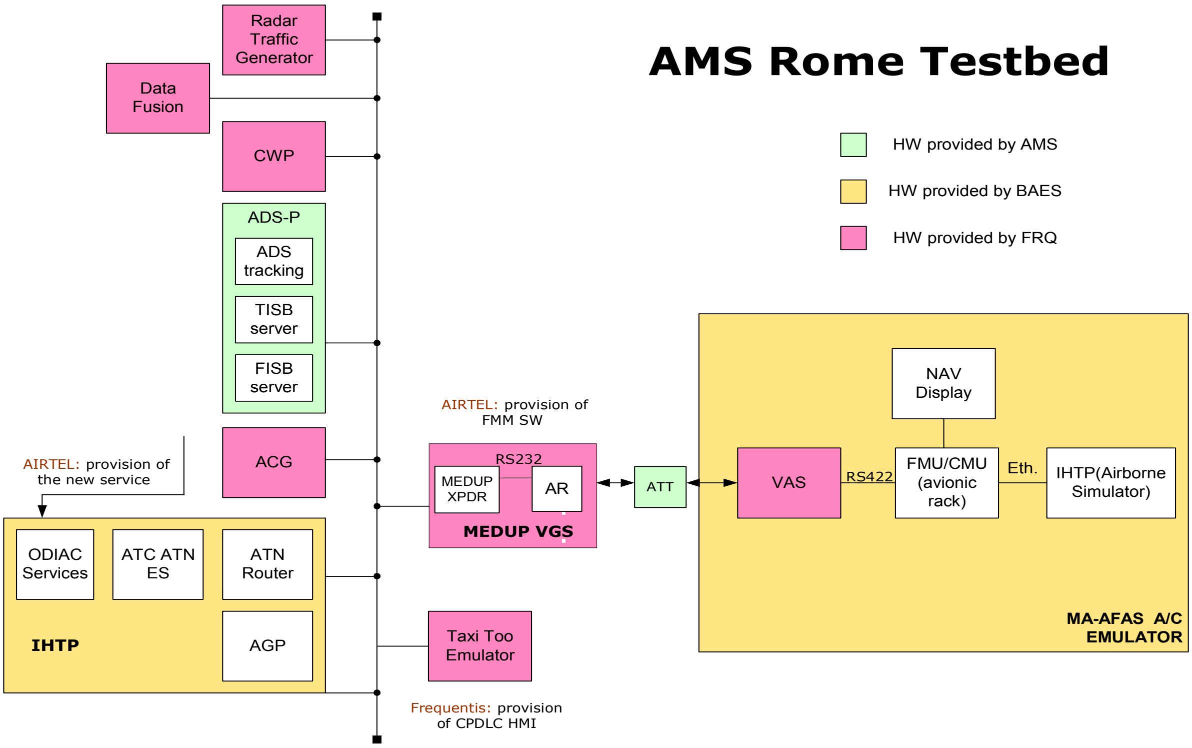


Figure 6.2-1: AMS Block Diagram

6.2.1.1 Subsystem Description

Subsystem	Hardware	Functional Description
		Ground Side
ADSP	Server	Sends and receives ADS-B messages from the a/c through the Communication Gateway; ADSP exchanges data concerning the flight plans with the FDPS; ADSP exchanges messages, like deviation or monitoring data alerts, with the CWP.
ACG	PC	The ATM Communication Gateway provides the support for each of the ATS data link operational services implemented within MEDUP: • ADS-B • TIS-B • FIS-B (ATIS)
DFP	Server	The Data Fusion Processor (DFP) is in charge of generating system tracks through the combination of any radar and ADS-B inputs.
CWP	Workstation graphics monitor 21''	The Controller working position provides the Human Machine Interface (HMI) to the controller. Its main functions are: • Display of surveillance information to ATC controllers, with the capability to indicate ADS-B equipped a/c. • Insert orders into the FDP associated with clearances and instructions issued during the progress of the flight.

Subsystem	Hardware	Functional Description
VDL4 Ground Station	Ground Station VDL Mode 4	The MEDUP VDL4 Ground Station (VGS) supports air/ground message exchange based on the VDL Mode 4 data link protocol
IHTP	PC	IHTP data link functions: • ATN A/G BIS Router • ATN ES • ODIAC Services • AOC Ground Platform Functionality
Taxi Tool emulator	PC+ PP	Exchanges taxi clearances with the airborne side
	Airborne Side	
VDL4 Airborne Station	Airborne Transponder VDL Mode 4	The Airborne Station is a VDL4 airborne transponder that enables the airborne user to communicate with the ground network for ADS-B, TIS-B, FIS-B.
NAV Display	VGA Monitor	Shows the TIS-B information
Traffic Simulator	PC	
IHTP (Airborne Simulator)	PC	Traffic simulator. Display for the FIS-B information (ATIS)
Avionics Rack (FMU/CMU)		Avionics Rack, MA-AFAS FMS and CMU

Table 6.2-2: Functional Description

To check the point-to-point (p2p) communications, the IHTP platform provided the ATN routing services. Figure 6.2-2 outlines the configuration of the point-to-point communications stack on the ground.

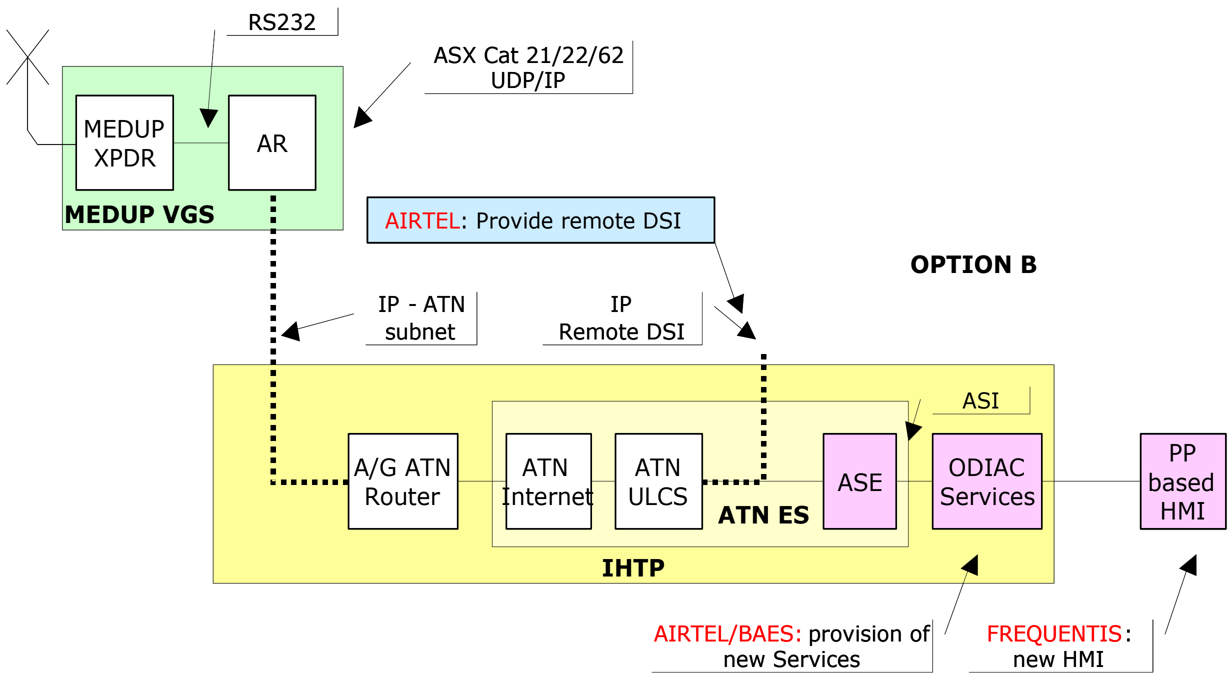


Figure 6.2-2: MA-AFAS Point-to-Point Communications

6.2.2 Shadow Mode System

In order to support the Rome flight trials, the MA-AFAS equipment was transferred to the ENAV Experimental Centre.

The approach utilised in the conduct of these trials was based on operating in a "*shadow mode*". This means that during the Rome trials, the ground and airborne sub-systems were fed with live operational data (e.g. radar tracks, flight plans), coming from operational ATC systems to which these sub-systems were connected.

Figure 6.2-3 contains the block diagram of the MA-AFAS system that had been installed at the ENAV Experimental Centre in order to support the Rome trials.

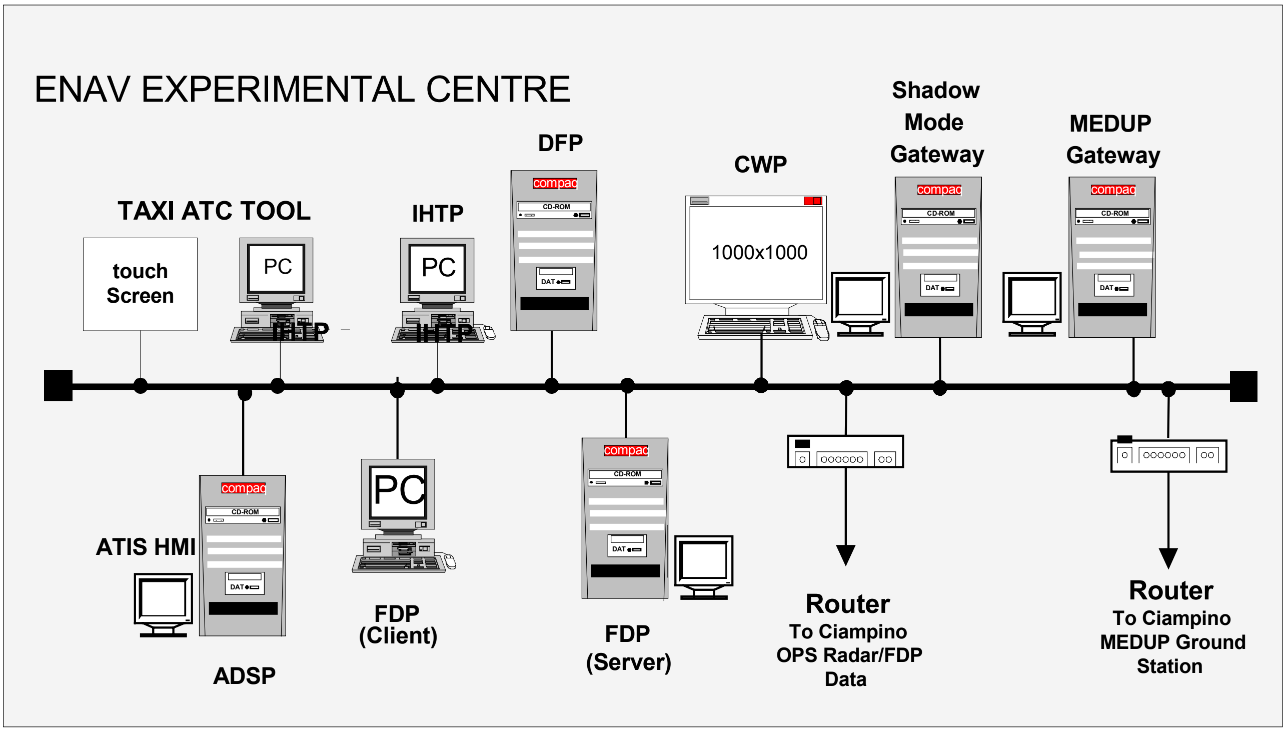


Figure 6.2-3: MA-AFAS Installation at the ENAV Experimental Centre

The MEDUP Ground Station was installed at the ACC in Ciampino and had been connected to the system located in the ENAV Experimental Centre through the Ground Station Router.

The ENAV LAN was used to interconnect the IHTP Platform with the MEDUP platform and the Taxi ATC Tool (TAT).

6.3 Communications Tests

This chapter covers all testing activities that were performed before the week of flight trials (24th-28th March).

The primary goal of these tests was to ensure that the MA-AFAS avionics would operate correctly when linked with the MEDUP Ground System.

It was also intended to check the range performance of the VDL4 data link relative to the MEDUP ground stations at Rome which were to be involved in the MA-AFAS trials.

These tests were mainly carried out at the AMS facilities, although after the move of the MA-AFAS equipment to the ENAV experimental centre, further checks were done while the aircraft was parked on the airport surface.

6.3.1 AMS Test Bed Communications Tests

The aim of these tests was to verify

- Integration of the MA-AFAS equipment in the AMS test bed,
- Interoperability checks that were performed between the MA-AFAS and MEDUP systems,
- Air/Ground communication testing of the MA-AFAS applications.

6.3.1.1 Test 1, ADS-B

The objective of this test was to demonstrate that the MA-AFAS Avionics Rack (FMU/CMU) could correctly communicate and exchange ADS-B messages with the MEDUP ground station (see Table 6.3-1).

Test descriptions	Result
FMU/CMU should generate ADS-B messages corresponding to aircraft trajectory simulated by the IHTP The ADS-B messages should be sent and received from the VDL4 transponder ACG should receive ADS-B messages from Avionics system and pass them to the ground system When the new report is received from the ground network, it should be processed by the ADSP The messages should be shown on the MEDUP CWP	These messages were processed and visualised correctly on the MEDUP CWP.

Table 6.3-1: ADS-B Test

6.3.1.2 Test 2, TIS-B

The aim of this test was to verify the VDL4 Ground Stations would operate correctly with the MA-AFAS avionics for uplink message transmissions, e.g. TIS-B, (see Table 6.3-2).

Test descriptions	Result
The Radar Traffic Simulator should generate and transmit TIS-B data The data should be processed by the ADSP ACG should receive TIS-B data from the surveillance system and pass it to the MA-AFAS Avionics Rack FMS should receive the TIS-B information This information should be shown on the NAV Display	Due to a problem detected in the code/decode algorithms, these messages were received by the FMS but not shown correctly on the NAV Display

Table 6.3-2: TIS-B Test

6.3.1.3 Test 3, Point-To-Point (P2P)

The aim of this test was to establish a connection between the ATN Air/Ground Router and the ATN Airborne Router (see Table 6.3-3).

This connection was done in two ways:

- ATN switch software running in the MEDUP GS. It is envisaged as the interface between the VDL Mode 4 ground station transponder and the ATN Router;
- ATN router directly connected to the VDL Mode 4 ground station transponder.

Moreover, the test verified that the ground IHTP could act as a gateway for the MA-AFAS functions (Taxi Clearance, AOC messages).

Test descriptions	Result
The power panel (PP) should generate the (e)CPDLC messages. These messages should be displayed on the MCDU (and vice versa).	This test did not succeed since the Ground ATN router was not able establish a stable connections with the Airborne ATN router. The time constraints did not allow further investigation of this problem

Table 6.3-3: Point-To-Point Test

Due to the difficulties encountered in establishing air/ground connection between the ATN routers, further AOC tests and those for the taxi clearances could not be completed.

6.3.1.4 Flight Test on 19th March

A flight was performed on the 19th March, aimed at checking the range performance of the VDL Mode 4 communications relative to the MEDUP Ground Station. This test was done with the QinetiQ BAC 1-11 aircraft, which flew out from the UK to the Ciampino airport before later that day returning back to the UK. The range check was to give confirmation of the feasibility of the routes chosen for the flight trials by ensuring continuous ADS-B coverage from the ground.

The objective of this test was therefore to verify that the ADS-B coverage from the ground station was complete over the whole trials area (see Table 6.3-4).

Test descriptions	Result
The ACG should receive the ADS-B messages from the airborne side and pass them to the ground system. The ADS-B report should then be displayed on the Controller Working Position (CWP), located in the AMS facility	From the ground point of view, the ADS-B report data was correct for the BAC 1-11 and was displayed on the MEDUP CWP

Table 6.3-4: ADS-B Air/Ground Test

It was decided not to perform other communication tests because these had not yet been successfully completed in the laboratory.

The main goal was to exploit the time during which the two aircraft were available on the Ciampino airport surface, in between the flight trials, in order to perform further communication tests.

7 Conclusions and Recommendations

The ground testing and validation of the MA-AFAS avionics package proved successful in terms of contributing to the development of the MFMS functionality prior to its use in the main flight trials. The ground test environment using the BAC 1-11 aircraft model rig was shown to be a valid representation of the aircraft, the levels of performance seen during the ground tests being comparable to those experienced during the flight trials. This can be witnessed by the fact that no flight was aborted or severely compromised because of any system problems. In this respect, the type of approach that was used within the MA-AFAS project for carrying out the development and testing should be seen as an example for future projects.

What was evident from the ground testing of the MFMS was that the requirement to produce software for a complete FMS proved to be a greater undertaking than had been anticipated. The original plan at the start of the project had been to use an existing FMS and produce software modules that provided the ASAS applications and associated functionality as additions to the standard FMS. When a change in organisational structure meant that the existing FMS software could not be made available, this placed a greater emphasis on developing and testing the basic FMS functionality on which the ASAS manoeuvre generator and communications elements could then be built. The overall result was that the ground testing of the system overlapped with the start of the flight testing, which consequently required a concentrated effort to maintain development with the ground system to support the progress of the flight trials.

The functionality of the MFMS was gradually extended through these ground tests to provide the capability for pass-behinds and the basics of the merge manoeuvre to be successfully flown, first with simulated traffic and then, for the Rome trials, with a live aircraft acting as the target. Further development continued to support the later trials with DLR's ATTAS aircraft to improve the merge-behind performance and to also add the ability to perform the other delegated ASAS lateral manoeuvres remain-behind and change spacing. The testing demonstrated that this type of functionality could be applied within a modern FMS, when supported by the additional HMI and communications applications.

The ground testing was able to support parallel development of the various components of the proposed ATM environment, incorporating the ATC/AOC functionality in the shadow ATC facility, the airborne functionality in the MFMS and the application of a data link communications protocol via the VDL4 system. Complete integration of all these components into the full ATM simulation was not achieved in the available time scales, principally the point-to-point communications being an area still requiring further development to reach the necessary performance levels for assessment within live aircraft trials.

The following recommendations are made to further the development of the MA-AFAS system:

- Development progress should be reviewed regularly and the development plan prioritised in accordance with the required objectives.
- Intensive ground testing against a representative aircraft model should be pursued as a primary objective.

- Although the project was limited, for technical reasons, to a single data link sub-system, further development of the data link and investigation of suitable alternatives is required to achieve a versatile and capable system.
- Further development of the ASAS manoeuvre capability is required to achieve an efficient and robust capability.

8 References

1. The More Autonomous – Aircraft in the Future Air Traffic Management System Simulation and Flight Test Plan – D32 of 29 Nov 2000. Report Number QinetiQ/FST/TR025809-D32.
2. The More Autonomous – Aircraft in the Future Air Traffic Management System Flight Test Validation Report – D39 of 30 June 2003. Report Number QINETIQ/S&E/AVC/CR031041-D39.

9 List of abbreviations

A/A	Air to Air
ACC	Area Control Centre
ACG	ATM Communication Gateway
ADS	Automatic Dependant Surveillance
ADS-B	Automatic Dependant Surveillance – Broadcast
ADSP	ADS Processor
A/G	Air to Ground
AGP	AOC Ground Platform
AMS	Alenia Marconi Systems
AOC	Airline Operations Control
A/P	AutoPilot
ASAS	Airborne Separation Assurance System
ASTERIX	All-purpose Structured Eurocontrol Radar Information Exchange
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATTAS	Advanced Technologies Testing Aircraft System
AvP	Avionics Package
BAGS	Broadcast Application Ground Server
CAS	Computed Air Speed
CCD	Cursor Control Device
CDTI	Cockpit Display of Traffic Information
CM	Context Management
CMU	Communications Management Unit
CNS	Communication Navigation Surveillance
CPA	Closest Point of Approach
CPDLC	Controller Pilot Data Link Communication
CRT	Cathode Ray Tube
CTOT	Calculated Take-Off Time
CWP	Controller Working Position
DADC	Digital Air Data Computer
DCP	Displays Control Panel
DFP	Data Fusion Processor
DLR	Deutsches Zentrum fur Luft- und Raumfahrt
DP	Data Puddle
EEC	Eurocontrol Experimental Centre
EFIS	Electronic Flight Instrumentation System
EIU	Engine Instrumentation Unit
EOBT	Estimated Off-Blocks Time
ETA	Estimated Time of Arrival
FDP	Flight Data Processor
FIR	Flight Information Region
FIS-B	Flight Information Service – Broadcast
FMS	Flight Management System

FMU	Flight Management Unit
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human-Machine Interface
ICCS	Integrated Civil Cockpit Simulator
IDRP	Inter-Domain Routing Protocol
IHTP	In-House Test Platform
ILS	Instrument Landing System
IP	Internet Protocol
IRS	Inertial Reference System
ISA	International Standard Atmosphere
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LCD	Liquid Crystal Display
LNAV	Lateral Navigation
MA-AFAS	More Autonomous Aircraft in the Future Air traffic management System
MCDU	Multi-function Control and Display Unit
MEDUP	Mediterranean Update Programme
METAR	Meteorological Aerodrome Report
MFMS	MA-AFAS Flight Management System
MTA	Managed Terminal Area
ND	Navigation Display
ODIAC	Operational Development of an Integrated Surveillance and Air/ground Communication
OOOI	Out, Off, On, In
P2P	Point-to-Point
PAD	Precision Approach and Departure
PC	Personal Computer
PRFL	Profile
RFS	Research Flight Simulator
RNP	Required Navigation Performance
R/T	Radio Telephony
RTAVS	Real Time All Vehicle Simulator
SBAS	Space-Based Augmentation System
SDB	Surveillance Data Base
SDP	Surveillance Data Processor
SID	Standard Instrument Departure
SIGMET	Significant Meteorological Report
SMG	Shadow Mode Gateway
SMGCS	Surface Movement Guidance Control System
STAR	Standard Arrival Route
SVGA	Super Video Graphics Array
TAF	Terminal Area Forecast
TAS	True Air Speed
TAT	Taxi ATC Tool
TCAS	Traffic alert and Collision Avoidance System
TIS-B	Traffic Information System – Broadcast

UP	User Platform
UTC	Universal Time Co-ordinated
VHF	Very High Frequency
VDL4	VHF Data Link Mode 4
VGS	VDL4 Ground Station
VNAV	Vertical Navigation
WP	Work Package
XPDR	Transponder

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