PROVISION OF DISTRIBUTED INTEGRATED AIR TRAFFIC MANAGEMENT DISPLAYS FOR THE GLOBAL SATELLITE COMMUNICATION, NAVIGATION AND SURVEILLANCE SYSTEM (GCNSS)

Abstract:

As part of the joint FAA / Boeing Air Traffic Management Global Communications Navigation and Surveillance System (GCNSS) Project, Embry Riddle Aeronautical University (ERAU) Air Traffic Management Laboratory was tasked with providing Display System Replacement (DSR) like controller displays to show live radar surveillance data and the Automated Dependent Surveillance data from the Connexion by Boeing aircraft operating outside both radar and VHF coverage. Communications was supplied by using Voice over IP and Controller Pilot Data Link Communications (CPDLC) both of which were integrated into the ERAU systems., The work entailed extending the ERAU real time ATM simulator from a LAN based system in a laboratory at Daytona Beach, FL; to a widely distributed system with displays at Houston Center, TX; Boeing ATM at McLean, VA; the Connexion Enterprise Operations Center at Irvine, CA; and even to on board the Connexion by Boeing aircraft airborne in the Gulf of Mexico. The paper covers the functional Air Traffic Management requirements, an overview of the design of the ERAU Real Time simulator displays, the integration and design of the voice and text over data link and the novel capabilities that were successfully implemented. The paper will also cover the technical detail of the software and hardware architectures upgrades including the embedding of live surveillance data and the extensive use of innate Internet capabilities to achieve advanced capabilities. Finally the connotations of the use of SATCOM, VOIP and CPDLC will be detailed and the implications of the successful trial of GCNSS for ATM worldwide will be discussed.

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BACKGROUND

The Boeing Company is investigating the architectural concepts, technologies and capabilities that can be developed and demonstrated to the FAA in response to their request for offer, analysis and demonstration of a global System Wide Information Management (SWIM) and broadband secure communications.

In particular Boeing produced a proof of concept demonstration to support the development of advanced system architectures, communication, and navigation and surveillance technology concepts with potential for implementation in the existing National Airspace System. This demonstration included dependent and independent aircraft monitoring and reporting; Automated Dependent Surveillance (ADS) fusion with radar data; and, advanced situational awareness. The intention of the demonstration was to show that it is possible to transition seamlessly between oceanic and domestic Air Traffic Management (ATM) using situation visualization and awareness, security and flight planning support tools.

The intention of the GCNSS project can be summarized as “to demonstrate that the current limitations of land based radar and VHF radio communications can be overcome by using existing satellite based technologies such as Ku and L band satellite communications and satellite based navigation using GPS. The investment that has already been made into these technologies can be leveraged to provide a truly Global solution to CNS/ATM problems without any new technological enablers being required”.

The Gulf of Mexico was chosen as the area to demonstrate the Global CNS System as there is no radar or radio cover in the center of the Gulf of Mexico and this leads to problems for both Mexico and United States air traffic management. The Gulf of Mexico also provided airspace that was neither too isolated nor too busy for easy operations of a live trial. Nevertheless, it should be stressed that, unlike other solutions to the Gulf of Mexico problems, the GCNSS functionality could have been successfully demonstrated anywhere in the world with no additional hardware or software.

GCNSS REQUIREMENT

The GCNSS Segment B requirement was for ERAU to provide a DSR like system that could provide an Air Traffic Control display and communications system that was capable of demonstrating the space based CNS/ATM concepts of the GCNSS. In particular the seamless transition of control from terrestrial radar and VHF communications to satellite based ADS surveillance and data-link, and the capability of the satellite based systems.

These requirements would require changes to the real time system. These changes included:

Wide distribution of the RTDS to provide 2 displays at each of Houston Center, Boeing ATM McLean, VA; Connexion by Boeing EOC, Irvine, CA; and, the Connexion by Boeing B737 aircraft

Provision of VOIP communications between the proxy-pilot[1], pseudo-pilots and controllers.

Provision of CPDLC communications between controllers, proxy-pilot and pseudo-pilots

EARL REAL TIME SIMULATOR

ERAU ATM Research Laboratory (EARL) has a Real-Time Distributed ATM Simulator (RTDS) with 8 control positions capable of simulating the use of ADS and radar and which can be linked to live external data sources. This simulator was enhanced for the demonstration to show data fusion between ADS and radar and it was widely distributed to Boeing ATM McLean, Virginia; Houston Center in Texas; the Boeing EOC facilities at Irvine in California; and full controller and pseudo-pilot displays were also in the Connexion by Boeing aircraft flying in the demonstration.

The enhancement of the simulator covered 4 main areas: Wide Area Distribution; Voice Over IP (VOIP); Controller Pilot Data Link Communications (CPDLC); and Display enhancement and integration.

Concept of RTDS

Due to its' object-oriented design, the EARL RTDS is a highly adaptable, scalable real-time distributed network-centric simulation. Moreover, the displays can be easily tailored to allow demonstrations of novel concepts.

The design concept behind the RTDS is the use of UDP Multicast messaging which mirrors the real world object behavior. This broadcast approach allows the addition of new components without adding to the communications load or bandwidth. Thus new controller or pseudo-pilot positions can be added: they receive the UDP-multicast messages and display what they are ‘interested’ in and discard other messages. The amount of traffic generated by human inputs into the displays is very small; therefore, there is no real architectural limit to the number of displays that can be added.

WIDE DISTRIBUTION

Every function within the RTDS follows the broadcast concept. This has allowed the progressive addition of capability to the system. In the GCNSS project it also allowed the simple addition of duplicate sectors at widely dispersed locations without impacting the operation of the RTDS. This required solving technical issues in extending UDP-multicast in some of the communications regimes imposed by GCNSS, in particular the Connexion by Boeing SATCOM links where specific tunnelling software was written by one of the authors to carry the UDP multicast packets through the EOC to aircraft link.

The network was implemented by Boeing ATM which provided a configuration of T1 lines between the GCNSS sites that was in a stellar layout with Boeing McLean as its hub. Each of the locations was equipped with a multicast capable router. The routers allows multicast aware components to pass multicast traffic to those who want it. The routers build a ‘tree’ of components that are interested in a

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[1] The proxy-pilot, a qualified pilot member of EARL, had a lap-top display that showed a full surveillance picture of the Gulf of Mexico, and provided VOIP and CPDLC.

particular multicast group. Multicast traffic destined for that group is received and forwarded to other reachable equipment that is interested in it. In this way, multicast traffic for a particular multicast group can branch out to networks interested in it without wasting bandwidth of those that are not In this way the RTDS wide distribution used the innate capabilities of Internet architecture.

Although the router in the Connexion by Boeing Enterprise Operations Center (EOC) supported multicast, the satellite connection between the EOC and the aircraft did not. The solution was to create a tunneling application to route TCP, UDP and UDP-multicast over the TCP satellite connection. The original plan was to use a standard software multicast router daemon to bridge the gap between the aircraft and the EOC. However, an intensive search on the Internet failed to locate any remaining and functional software router daemons. The end result was to write an application that creates user definable tunnels to transport packets. The tunnels are defined by the user in a configuration file read at startup.

DATA INPUTS

The RTDS received surveillance data from the Surveillance Data Network (SDN). The data was collated at Lincoln Laboratories, Bedford MA; from ADS outputs from the Boeing aircraft and radar beacon plots from the 'preferred' radar for each aircraft position. The surveillance data was in the form of CORBA objects carrying the aircraft beacon code as an identity and flagged as either ADS or a radar position. The objects also gave flight level/altitude, speed and the rate of vector change.

If the CORBA object referred to an aircraft that had not yet been displayed the RTDS created a new aircraft object, otherwise the information from the object was fed to the existing aircraft object. The aircraft objects in the RTDS then broadcast their position and vector state in ADS-B RTCA DO-242 format over an internal VHF Data Link (VDL) channel.

Simulated aircraft objects were also flown in the RTDS automatically following their flight plans until a pseudo-pilot took control of them. These simulated aircraft also broadcast their position and vector state in ADS-B RTCA DO-242 format over an internal VDL channel. From the point of view of the RTDS displays real and simulated aircraft were identical.

VOICE OVER IP (VOIP)

There were two VOIP systems trialed during the GCNSS flights: a Connexion by Boeing developed system using commercial SIP compliant software based on Microsoft Messenger software; and, the Java based VOIP application.

EARL had developed the in house VOIP capability to provide an expansible and flexible VHF emulation. For GCNSS the RTDS VOIP would be used to provide high quality voice communications to aircraft operating outside VHF radio coverage. It should provide the same capability as VHF in which all parties on a frequency can hear all other parties.

The GCNSS project was also used to demonstrate capabilities that are only available with VOIP. These were:

Step-On Prevention. This system prevents the 'two aircraft at once' problem repeatedly encountered in normal VHF radios. The VOIP system only allowed one aircraft to transmit at a time and muted the others.

Controller Precedence. Controller precedence gave controllers the capability to break into any aircraft transmissions. As a common problem that controllers have with a busy sector is getting a time for transmission themselves this can also occur with 'stuck transmit switches'.

Automated Handover of Voice Communications. With VOIP it is possible to transfer voice communications to another controller just by altering the multicast IP that the aircraft. This removes the error prone transfer of radio frequency.

The VOIP application runs on standard PCs and their soundboards. Stereo headsets were used with controllers receiving R/T on one side and controller-controller communications on the other. Although available the controller-controller communications were not used. A press-to-transmit switch, either hand or footswitch, was connected to the parallel port of the computer.

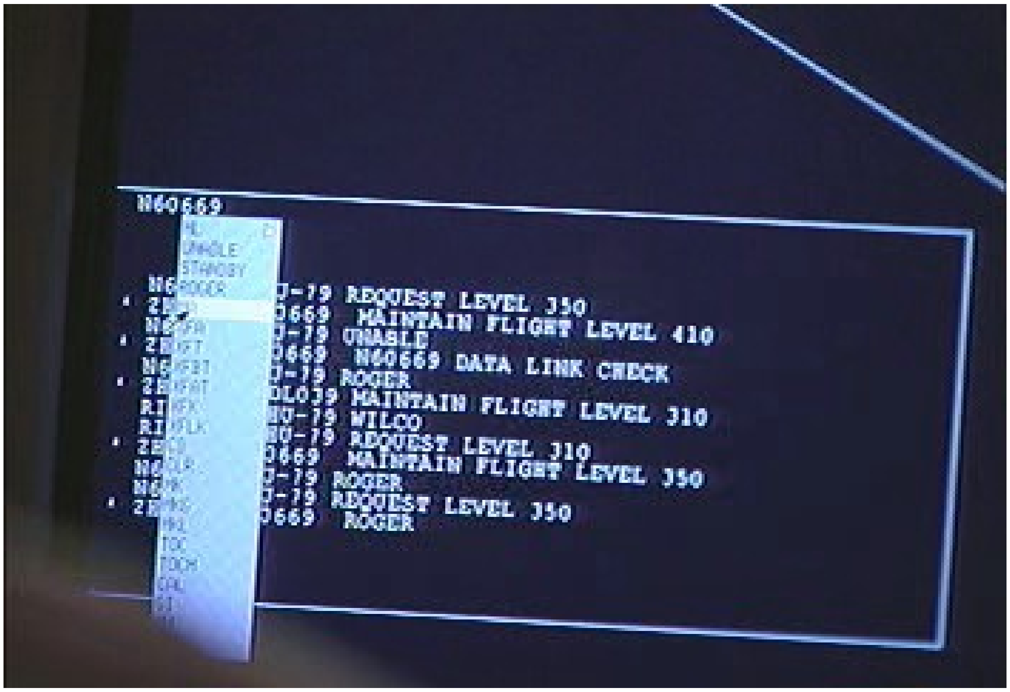
For the Connexion by Boeing aircraft the same facilities were made available over KU band. However using Iridium phone, L-Band, an analogue bridge was used. A standard ‘iridium call’ was made to the EARL this was fed through a circuit providing VOX and feedback prevention that acted as an automatic transmit switch. The analogue speech signal was fed into a PC soundboard and processed identically to the controller and pseudo-pilot VOIP. In this way the Iridium phone call joined the multicast group and had all the same capabilities.

VOIP was closely integrated with the RTDS and the VOIP software monitored the status of transfers of control. When an aircraft was ‘assumed’ on silent handoff, the VOIP initiated the automatic handover of voice communications.

CPDLC

The EARL simulator already used CPDLC to communicate with aircraft objects. However, for the demonstration it was required to provide several levels of CPDLC from the variant in operational use through to Builds 1/1a/2 message sets. Due to these differing flavors of CPDLC a simple message system was developed as part of the display processing.

To avoid getting involved in discussions on the merits of the differing CPDLC message sets and standards, a simple pull down menu for messages was generated that was populated through a configuration file. This allowed any messages to be provided. The pull down menu initially showed a message code (e.g. MH for Maintain Heading) as the message was composed the message code was expanded into an abbreviated message and the cursor positioned at the first blank field, if any, to be completed. When the message was received it was expanded into the full verbose message for ease of understanding.



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J-79 REQUEST LEVEL 350
0669  MAINTAIN FLIGHT LEVEL 410
J-79 UNABLE
0669  N60669 DATA LINK CHECK
J-79 ROGER
DL039 MAINTAIN FLIGHT LEVEL 310
NU-79 WILCO
NU-79 REQUEST LEVEL 310
0669  MAINTAIN FLIGHT LEVEL 350
J-79 ROGER
J-79 REQUEST LEVEL 350
0669  ROGER
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Figure 1. Screen Shot of CRD Showing Initial Drop-Down CPDLC Menu (Note the Asterisks on Output Messages Indicating Logical Acknowledgements

The Miami implementation of CPDLC supports a ‘menu list’ of standard preformatted messages for each sector. The EARL implementation also supported this as a second level menu. The controller selected ML (Menu List) and was presented with a second drop down menu of messages for selection.

When the message was sent by the controller it scrolled down from the compilation area on the CRD. When the message was displayed on the target display, that display transmitted a ‘Logical Acknowledge’ back to the originator, which was displayed as an asterisk alongside the message.

There are a very limited number of single word responses to CPDLC messages. The allowable responses were presented to the proxy-pilot or pseudo-pilot for their choice of response. When the response was sent it not only appeared under the sent message in the controllers CRD but also as a bottom line of the data block in yellow for 20 seconds . Thus a controller whose attention was on the surveillance display would not miss a CPDLC response.

Functionally and architecturally the CPDLC capability was actually part of the display processing. This close integration extended to the silent handoff. When a controller initiated handover by ‘flashing’ the data-block to the next sector, the display CPDLC process read the message sent and initiated a “NEXT DATA AUTHORITY [sector name]” message to the aircraft being handed over. When the next sector assumed control of the aircraft the display CPDLC process issued a “CURRENT DATA AUTHORITY [Sector Name]” message. As these messages were automatic the controller workload at handoff was minimized but the messages improved the pilot situational awareness notifying them of completion of the handover process.

CONTROLLER DISPLAY

The intention of the displays was to be close to, but not identical with, normal DSR displays. The objective of the demonstration was to demonstrate the concepts of seamless surveillance using space based and network centric surveillance and integrated CPDLC and VOIP over satellite geostationary KU and L band (LEO) Iridium. The display was to show the radar and ADS responses for each aircraft and not a single fused track-plot. This was to highlight the change from radar to ADS over SATCOM. The update rates of the radar(s) and ADS were different. The standard NAS surveillance radars update about once every 12 seconds. The ADS from the Connexion by Boeing B737 was updated every second.

The differing update rates and the mix of traffic some with only radar and some with both radar and ADS and some with only ADS meant that the flight data block and any predicted vector, had to be linked to the surveillance position that was the ‘most accurate’. This meant that if there was ADS the label was connected to that, otherwise the label was connected to the surveillance radar position.

The flight data block format used was based on the standard NAS DSR format. But other indicators were required to show that aircraft were ADS, CPDLC and VOIP equipped and whether they were logged in to the data-link service. The implementation in Miami was considered, however, it used a set of symbols that would require explanation to observers that were unused to it.

As shown in Figure 3 the position symbol for ADS was added as a small circle with trail dots. The indication that the aircraft was data-link equipped was to highlight the ‘not under control’ **R** in blue and when the aircraft was under control add a small ‘ ‘ symbol. This relatively simple symbology was easy to explain. Also, unlike the Miami approach it meant that data-link eligibility to an aircraft was linked to the eligibility to control the aircraft. There were many discussions on this point.

◣ ABC123
370C
317 425

CPDLC session established but sector with display does not have 'data-link eligibility' for CPDLC messages

ABC123 ◣
370C
317 425

CPDLC session established and sector with display has 'data-link eligibility' for CPDLC messages

Figure 2, Example Miami Center Display Format for CPDLC Eligibility

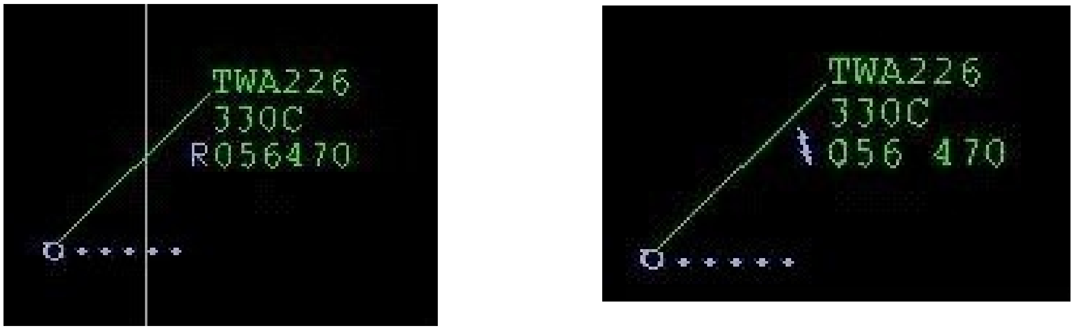

Figure 3. Example EARL GCNSS Display ADS Aircraft Logged in Not Under Control

Figure 4. Actual Demonstration Display

Figure 4 is a screen shot of the display in Houston Center Dysim during an actual demonstration flight. The center of the screen is about 150NM south of New Orleans. The aircraft N60669 closest to the center of the picture is the live Connexion by Boeing B737. The radar trail is still behind the aircraft but there is no longer any radar coverage. The other aircraft in the figure are simulated aircraft with the callsign RIDLnnnn they were being ‘flown’ by pseudo pilots in EARL

The display was provided a fully integrated capability demonstrating that both VOIP and CPDLC could be linked to silent handoff so that the normal workload associated with transfer of communications at handoff could be reduced but without the pilot losing situational awareness. When the controller initiated handoff by clicking on the aircraft and entering the next sector number, the CPDLC process issued the Next Data Authority message to the aircraft warning that the handoff was in progress. When the next sector assumed the aircraft by clicking on its display, the VOIP voice communications were moved to the assuming sector and the CPDLC issued the Current Data Authority message telling the pilot the sector that is now has control authority over his aircraft.

The result of the integration was that transfer of control of the aircraft required no extra effort by either the controller or the pilot and was error free. This is one of the main drivers of workload in some sectors so in operational use it could increase capacity by reducing the controller workload.

The display hardware was provided by Barco who supplied 6 2K*2K flat panel Isis displays. These displays were connected to the normal EARL controller workstation by a direct Ethernet connection through a VisionA display processor.

SCENARIOS

The demonstration scenarios involved flying the Connexion by Boeing B737 out to an exercise area in the Gulf of Mexico that was agreed with Houston Center. The aircraft flew within this large box entering at about 22:30 local time and exiting about 3 hours later having flown an exercise route within the area at least 4 times. Each leg was flown either using KU or Iridium as the communications and the controllers also switched to using a Connexion by Boeing VOIP system based on the SIP protocols and run using Microsoft Windows Messenger software.

Figure 5. GCNSS Ocean West Demonstration Controller at Houston.

Also in the exercise area were simulated aircraft being flown by EARL pseudo-pilots. As shown in Figure 4 they appeared identical to the controller and lost radar positions when they flew outside the radar cover of the radars around the Gulf of Mexico. The simulated aircraft were flying tracks that the Houston control staff had said would be useful for Gulf of Mexico transit aircraft or those that would normally be difficult for controllers in the Ocean sectors. They were crossing the center of the Gulf of Mexico from Cypress (just North West of Miami direct to San Antonio in Texas, others were climbing out of airports in Mexico northbound toward New Orleans. The simulated aircraft were used to provide 'interfering traffic' for the controllers to handle and avoid. From the controller point of view the simulated and live aircraft appeared identical.

There were 3 formal demonstration flights in the Gulf of Mexico. The first 2 flights were intended to use relatively basic CPDLC services. The final flight was intended to use more complex control with CPDLC and VOIP to demonstrate that the space based capabilities were sufficient to provide 'en-route' control in areas that had no terrestrial radar or radio. Controllers found the CPDLC easy to use and it appeared completely adequate for non-tactical controlling such as clearances to climb above weather or climbs to levels for strategic separation. The VOIP voice communications both the integrated EARL VOIP and the Connexion by Boeing SIP based VOIP showed that voice communications were extremely high quality and that they should be suitable for en-route control.

During the run up trials to the formal demonstrations the GCNSS project teams had watched the ADS output from the Connexion by Boeing aircraft showing it taxiing and taking off. Nevertheless, as an unarguable demonstration of the capability of the system, the trials aircraft was descended to an altitude of 10,000 feet in the southern part of the exercise area definitely well out of all normal VHF and radar. Throughout full voice communications over VOIP and CPDLC and continuous ADS surveillance were maintained. The flights were then monitored all the way back to into at New Orleans airport and ADS surveillance was continuous until the aircraft powered down on the ramp.

ACHIEVEMENTS

The GCNSS project provided many challenges to the EARL project team some of which were completely novel and unexpected. The solving of these issues led to significant achievements both for EARL and for the GCNSS team as a whole. In summary:

Embedded Live Aircraft in Simulator. The RTDS had live surveillance data both radar and ADS embedded into a simulation. Thus live and simulated aircraft were displayed identically to the controllers.

Widely Distributed Simulation. The RTDS was designed to run on a LAN within the EARL which emulates a DSR bay. This simulation was successfully widely distributed across the Boeing supplied WAN, to Texas, California, Virginia and even to the airborne Connexion by Boeing aircraft. All the widely distributed 'sectors' had the same functionality and shared all inputs and outputs; and worked without problems throughout the demonstrations.

Real-Time TIS Displays in Aircraft. The information broadcast on UDP to the RTDS displays from the target generator or from the surveillance inputs, was in the RTCA DO-242 ADS format. The proxy-pilot's display in the aircraft received these transmissions and displayed all traffic in the Gulf of Mexico area both the live radar and ADS and also the simulated aircraft. This was therefore in fact a live demonstration of Traffic Information System-Broadcast (TIS-B) although contained in the TCP tunnel.

VOIP. The demonstration showed that VOIP provided a superior sound quality to VHF radio. Furthermore, VOIP using UDP-multicast has no requirement for a central server, adding fault tolerance at no cost, and more importantly, the lower network layers maintain a continual connection between aircraft and ground system; as soon as there is a failure it would be flagged without waiting for a transmission to indicate there had been a failure; also improving safety.

VOIP and VHF. As VOIP can share a VHF frequency with other VOIP data transmissions, it could lead to a great reduction in frequency congestion. Subjective testing by controllers at Houston showed no problems with the transit time of either KU or L band satellite.

Integrated VOIP. Voice over IP was fully integrated with the controller displays allowing silent hand off of communications between controllers without adding any extra tasks. If this were to be used in practice the workload on sectors could be decreased significantly leading to increased sector capacity.

VOIP Enhanced Capabilities. VOIP prevented 'step on' where one aircraft transmits over another it also provided controller precedence allowing a controller to break into any aircraft transmission. Both capabilities would reduce major problems that can occur with 'normal' VHF R/T.

VOIP for *All* Voice Radio Systems. The VOIP on L-band over Iridium used an 'analogue bridge' where a normal Iridium analogue phone connection was linked via a VOX box to a sound processor which then linked the Iridium phone into the VOIP system. The effect was to provide all the VOIP capabilities to the Iridium analogue phone: all the pseudo-pilots and the controllers on the VOIP broadcast group could hear the live aircraft on Iridium and the live aircraft could hear all the other parties. The Iridium connection could also be handed off in the same way as a 'normal' VOIP connection. This demonstrated that VOIP capabilities could be provided for **any** users with analogue voice communications without any need for them to re-equip with digital systems.

Integrated CPDLC. CPDLC was fully integrated with the displays. The CRD was used as normal for message in and out, but responses were also shown highlighted in yellow as a bottom line on the aircraft flight data block. Moreover, CPDLC messages were issued automatically on silent handoff warning the aircraft of a data authority change and showing when hand off was complete. All these messages were transparent to the controller and generated no extra workload.

Flexible CPDLC. The CPDLC system in the EARL RTDS was based on a flexible drop down menu system that could generate any of the many flavors of CPDLC, the Miami Center CPDLC message set, and the Build 1, 1a and 2 message sets. As CPDLC is *meant* to be between a human controller and pilot, this would appear to be a flexible model for operational implementation.[2]

Proxy Pilot Display. Throughout each live flight the proxy-pilot had a full ATC display of the live and simulated aircraft in the Gulf of Mexico. The display indicated which sector was controlling aircraft and whether those aircraft were data-link equipped and logged in. If it had been required the proxy-pilot could have called up the current cleared flight plans of any of the aircraft. The proxy-pilot display had integrated VOIP and CPDLC communications running over SATCOM when the aircraft was outside the range of terrestrial radar and VHF radio. This type of display would greatly improve the situational awareness of pilots.

Geographically Independent CNS/ATM. The Connexion by Boeing aircraft position was being displayed on all displays country wide, accurate to a few metres, with altitude, vertical rate, and turn rate. This is an accuracy only matched by precision talk down radars. The demonstration showed unequivocally that this same capability can be made available anywhere in the world using existing deployed technology.

CONNOTATIONS AND CONSEQUENCES

In a busy sector, a high percentage of controller workload can be caused by hand-off of control and frequency changes. The auto-handoff demonstrated with the EARL VOIP would remove a major source of workload and errors. This would increase capacity and safety

The current VHF spectrum is extremely crowded. Using simple R/T, one frequency has to be allocated to each sector and that frequency cannot be used for other purposes within aircraft line of sight: However, VOIP can share a single VHF data-link connection with other multicast messages. Therefore VOIP has the potential to reduce or remove the current frequency congestion that has led to the mandated introduction of radios with 8.33Khz frequency spacing for aircraft operators.

The capability to provide a party-line facility (everyone on a multi-cast IP hearing everyone else) is far more powerful than an merely emulation of VHF. An aircraft over the Pacific could be on the same

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[2] There should be another data-link interface standard for Flight Management System ground Air Traffic Control system communications that is not limited to stylized R/T syntax.

multicast as an aircraft over the middle of Europe and hear each other in the same way. This makes party line voice communications independent of geographic location.

The analogue bridge technique used for linking Iridium phone into the VOIP multi-cast group could be applied to any sound device, such as a normal telephone, an HF link, a handheld radio, a cell phone etc. without any change being made to those devices. The devices would then have all the facilities of VOIP and could be interlinked in one geographically dispersed party-line multicast group with all the associated VOIP functionalities

As with all the EARL applications the VOIP made use of the innate capabilities of the internet UDP-multicast protocols which were developed for streaming data across the internet without transmitting more than once over any branch between routers. This approach has the potential to be applied to other applications. For example, in segment A hand-held PDAs were used to send video point-to-point over the SATCOM, using the multi-cast and tunneling communications approach a flight marshal's streamed video could be multi-cast to other security personnel without geographic limit.

CONCLUSION

The GCNSS Demonstration project was challenging at many levels. The EARL Real Time Distributed simulation was upgraded to allow embedding of live external surveillance data; and was distributed over a WAN including SATCOM links with integrated CPDLC and VOIP. Each of these functions in their own way was a challenge. Perhaps the most difficult being the tunnelling of UDP-multicast through the WAN and over SATCOM to the aircraft. A similar challenge was the development of the hardware VOX and associated circuit that make linking of any analogue voice into VOIP possible.

Live radar and ADS data was received as CORBA objects from the SDN and aircraft objects were created that were equivalent to the simulated aircraft objects. These aircraft objects then internally re-broadcast their surveillance positions to the display processors. . The display symbology was simplified to show the surveillance type and data-link status. The demonstration flights over the Gulf of Mexico exercised the integrated RTDS systems; including displays with VOIP and CPDLC; widely distributed over the country and even into the Connexion by Boeing aircraft.

The live demonstrations showed seamless transition between the radar and ADS SATCOM domains, control by VOIP and CPDLC with the live aircraft being manoeuvred around simulated conflicting aircraft These demonstration flights unequivocally showed that SATCOM based CNS/ATM is both feasible and achievable using currently available and deployed technology.

Historically, as communications have improved, air traffic control service operations have progressed from being inside a hut or truck under a radar antenna, to airport buildings then to remote centers. There is now no need for even the air traffic control centers to be within the bounds of the airspace they are controlling. With the facilities demonstrated by GCNSS, built entirely on existing technology, it would be possible to provide air traffic management services to anywhere in the world *from* anywhere in the world. Air traffic management could become an export.