Title: Airspace Concept Evaluation System (ACES), Concept Simulations using Communication, Navigation and Surveillance (CNS) System Models

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Abstract: With the current FAA, Operational Evolution Plan and the US Department of Transportation, Integrated National Plan for the Next Generation Air Transportation System (NGATS) currently focused on the need to ensure that the U.S. NAS meets safety, security, mobility, efficiency and capacity needs of the future, the continued development of improved resources for the study of new NAS concepts to support this initiative are required. These resources take on many forms, but as primary tools for evaluating new concepts to meet these objectives, simulation tools for NAS concept operations continue to play a key role. These tools, if properly designed and progressively upgraded to provide improved real-world capabilities are essential to this effort. One such tool, NASA's Airspace Concept Evaluation System (ACES), is an example of a simulation environment that has proven very effective for these concept studies, and which has continued to undergo improvements to enhance its capabilities. One recent improvement that ACES has adopted, is the inclusion of CNS system modeling capabilities. These systems, legacy systems currently used in the NAS and newer technology systems that are under consideration, are in a state considerable evolution and evaluation for their ability to support NAS and CNS architectures that will support the functional reality of future airspace operations. With the addition of CNS system models in ACES, CNS systems performance can be evaluated in large-scale simulations and for simulations directed at specific details of NAS operations. Also with this system simulations and analysis can be done that addresses the performance of the CNS systems themselves to support future NAS operations.

With the completion of the development effort to integrate Voice Communication, CPDLC, SSR and ADS-B surveillance, and GPS and VOR/DME navigations system models, and improvements to their configurability for CNS simulations by late FY06, many new simulation opportunities will exist in ACES. For future NAS concept studies, this paper presents information describing the new ACES CNS modeling capabilities and their configuration options. The paper presents ideas on how concept studies with ACES can be augmented by parallel CNS systems simulations. Also identified are ideas on what new CNS studies could be considered to evaluate CNS system operation and CNS architecture definition. Results of sample concept scenarios are included to support these opportunities.

Introduction

Concepts to investigate solutions to air traffic capacity increases in the future National Airspace System will not only require evaluations of physical aircraft dynamics to demonstrate successful proof-of-concept, but will also require evaluations of the ATM supporting infrastructure to support these concepts. The Airspace Concepts Evaluation System (ACES), developed as a simulation tool to provide NAS concept investigations, identifies this as a basic objective as presented in its system definition stating that, "Concept studies that ACES models fall into one of three basic categories: Agent, Infrastructure, or Environment", and continues to say, "Put simply, NAS Agents operate within the NAS Environment and communicate with each other and the NAS Environment through the NAS Infrastructure". That infrastructure, which includes systems to communicate with pilots, systems to communicate information to and from aircraft, systems that provide information onboard aircraft to the cockpit, and systems that provide awareness of traffic conditions to controllers on the ground, (i.e. Communication, Navigation and Surveillance systems), are essential systems whose ability to support a concept may dictate concept success or failure if not properly implemented.

To provide added infrastructure simulation capabilities in ACES, a baseline set of CNS models were integrated during FY05, and enhancements and new models that are currently in the process of being added as a deliverable to ACES by NASA GRC.

This paper provides a brief overview of the CNS system models and enhanced capabilities that make use of these system models to add more realistic infrastructure airspace operations in ACES. Results of testing of select systems are provided as well as results from selected enhanced features. Also presented is an assessment of a simulation, presented as a sample concept idea, with results to indicate how communications simulations can be applied for studies with ACES that previously could not have been considered.

Model Descriptions and Enhanced Features

Communication System Model

For Air Traffic Management, voice communication is the primary communication mechanism between the pilot and Air Traffic Control facilities (Tower, TRACON, ARTCC, etc.) in the present NAS. Message exchanges for directing airport gate departures, ground traffic instructions, take-off clearances, landing sequences, air route change information and aircraft maneuvers as well as air-space, region and sector-to-sector transitions are typical voice sequences that occur via voice communication.

As the default communication model component, a voice communication system model is provided, simulating voice message exchanges that are typical for gate-to-gate

aircraft/flight operations. The simulated voice communication system transmits messages using a VHF radio model to provide voice message delivery with exchange characteristics and protocols that provide representative delay and message collision handling capabilities.

During FY06, Controller-Pilot Data Link Communication (CPDLC), an application that provides a means of communicating digital data messages directly between computers on the ground and computers on board the aircraft for ATC communications, is being added. Use of this system for communicating messages for Air Traffic Management will help to alleviate frequency congestion problems, and allow the controller to handle more traffic. In its simulated implementation in ACES, the CPDLC system model will represent CPDLC messaging for air-to-ground services as derived from a combination of CPDLC, Baseline 1/2 and RTCA DO-269 specifications. The CPDLC messages will be applied to be consistent with the message set and airspace operations for the modeled Voice Communication system. The data link radio model employed for the CPDLC system is a VHF Data Link - Mode 2 (VDL-2) model.

For both Voice and CPDLC Data link communications the modeled systems provide equivalent message sequences synchronized with ACES Flight events for each aircraft. Message sequences are provided for surface operations, departure and arrival TRACON operations and en route events where communications with the aircraft are normally conveyed for ATC-to-Pilot instructions. Message context and control parameters used by the radio models for simulated transmission of messages are available to both systems from user-reconfigurable configuration files, and other data such as ground station locations, ground station radio parameters, aircraft equipage,… can also be modified as required.

The Voice and CPDLC system models operate in a similar manner within ACES, distinguished by their message type and the radio model used for message transmission. As ACES timing or events dictate, transmission of messages are directed from a flight or ATC Agent (as the sender agent) through the appropriate communication/Radio link model and on to the destination flight or ATC agent (as the receiver agent). Both the transfer of a particular communication message to the communication model and subsequent movement of the message from the model to its destination are handled using the publish/subscribe operations provided in the Agent-based simulation environment. Output parameters that identify message delivery success and performance characteristics of the end-to-end (sender to receiver) transmission of a message will be stored in output databases for experimenter analysis.

As well as providing operation of the communication system models, three additional features have been added that can be used in parallel with communication system modeling to more realistically simulate its NAS implementation. These

include: 1) Communication Activated Maneuvers - which provides a sequence of ATC/Pilot, instruction and instruction acknowledgement messages that are required to be delivered successfully before an aircraft maneuver can be initiated, 2) Enhanced Frequency/Channel allocations that provides more realistic distribution of voice messages over multiple channels within the TRACON and airport airspace for specific airports, and 3) a Short Sector Transition Time feature that mimics ATC control of whether a new frequency is communicated to an aircraft when the length of time the aircraft will reside in a portion of a sector is limited.

Navigation System Models

System models for VHF Omni-directional Range/Data Measuring Equipment (VOR/DME) and Global Positioning System (GPS) will be available as Navigation systems in ACES.

Used as a standard technology for navigation in the National Airspace System, VOR/DME is a ground based electronic navigation system that is provided as the default Navigation model to generate simulated latitude/longitude information available to the aircraft. In its operation, VOR facilities transmit signals at the same time and electronically compare the difference to interpret the result as a radial from the station. VOR is enhanced through use of DME systems. DME equipment onboard the aircraft transmits a stream of interrogations to the ground station, comprised of a pair of RF pulses, which are responded to by the ground stations. The airborne DME equipment receives the reply and measures the elapsed time (transmit to reply) to calculate the round-trip time. From this, it can determine exact distance from the ground station to augment position information available to the aircraft.

The VOR/DME model provided is a statistical model implemented as a navigation activity of the Flight Agent. The true position (state information) of the flight is used by the navigation activity to compute the reported position by adding a VOR/DME equipment error to the true position. Also during the simulation, slant distance is calculated by the navigation activity for every aircraft location update using the next VOR/DME ground station location encountered by an aircraft.

With the increasing use of GPS navigation equipment onboard aircraft to augment traditional systems, a GPS statistical model is in the process of being added as a second Navigation system model. GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but is now available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. GPS receivers placed onboard aircraft are beginning to see more widespread use as secondary navigation devices for use

within the NAS. GPS data on board aircraft can be provided to other onboard systems.

The GPS model that will be introduced in ACES is also a statistical model implemented as an activity of the ACES flight agent, as an onboard system. As with the VOR/DME model, the GPS model obtains true position data by subscribing to flight agent, flight physics activity, state messages. The GPS model will provide varied GPS system accuracies, implementing Local Area Augmentation System (LAAS) accuracies for airport airspace and Wide Area Augmentation System (WAAS) accuracies for en-route airspace.

As an added capability to enhance the use of the navigation modeling in ACES, a closed loop operation feature was recently introduced. With closed loop operation for navigation, the system provides feedback of the navigation system model output (reported position) to the aircraft flight agent. With this information, as would be the case where a pilot or autopilot would use the data for steering, the aircraft will see its position varied somewhat from its desired position (due to the imprecision of the navigation system), and therefore steer the aircraft to correct for the errant location. With this feedback, and depending on the accuracy of the navigation system information, it is anticipated that a more accurate representation of flight trajectories and flight times may be realized.

Surveillance System Models

For Surveillance, two surveillance system models will be available, Secondary Surveillance Radar (SSR) and Automatic Dependent Surveillance – Broadcast (ADS-B).

In the current NAS, ground-based, Primary Radar systems are complimented by Secondary Surveillance Radar (SSR). Both systems are used to determine the presence and position of planes in the airspace allowing controllers to track each plane precisely and efficiently.

For surveillance system modeling in ACES, an SSR model is implemented as the default system. The SSR model operates in a similar manner to navigation models, using Flight Agent true state data as input, and applying statistical performance characteristics to provide a new reported position. The model is integrated as an activity of a Surveillance Agent, represented as ground based agent due to the inherent surveillance system ground based data processing and subsequent delivery of these systems data to air traffic controllers. For its operation, the SSR model receives ACES aircraft state data as its input for processing using a publish/subscribe operation, and simulates delivery of data as available to ATC on the ground.

ADS-B equipped aircraft automatically broadcast latitude and longitude, velocity, altitude, heading, identification and, optionally, intent as determined by the avionics on board. This information is broadcast via data link to ADS-B ground

stations, other ADS-B equipped aircraft and ground vehicles. The data captured by ADS-B ground stations is distributed to Air Traffic Management (ATM) and other control systems. As a modeled surveillance application, ADS-B is simulated for Air-to-Ground broadcast only (i.e. Aircraft Transmit, Ground Station Receive) using Mode S, extended squitter as the communication link. Onboard the aircraft ADS-B will use simulated Navigation system output data (VOR/DME or GPS) for the aircraft position (i.e. latitude, longitude), and ACES flight physics model output for aircraft altitude, velocity, heading, and aircraft Flight ID as input for messages.

In adapting the ADS-B application to the ACES environment, this system model uses a combination of the methods used for communication systems and for the SSR model, and takes input from the navigation system that is selected for the simulation. For ADS-B an activity of the flight agent was created as a sender activity that receives data from the Navigation model. The output of the sender activity (as a published message) then provides an ADS-B message to a communication agent, Modes S Radio Model activity. If the Mode S model determines that favorable conditions exist for message delivery success, the ADS-B message is then transferred to an ADS-B receiver activity of the Surveillance Agent. This system therefore represents the monitoring and reception of ADS-B data again at the ATC location where the tracking of the aircraft is taking place.

Similar to the closed loop operation feature added for navigation after the baseline development, an added capability to enhance the use of the surveillance modeling data in ACES was also implemented. With the surveillance system closed loop operation, a simulation can be configured to provide feedback of the reported surveillance system model output (reported position) to ATC agents in ACES. With this information, as would be the case where a controller would see an aircraft out of expected position, ACES NAS agents might use the data to generate new maneuvers for the aircraft, or may identify traffic restriction violations due to the variation of the aircraft from it anticipated/desired position, leading to more realistic and dynamic flight scenario.

System Model tests results

Testing of the Voice Communication, SSR and VOR/DME modeling was completed in September of 2005. Requirements test simulations were done to verify the system model operation and system/model configuration capabilities. Additional characterization tests were also run with varied Flight Data Sets (FDS) to identify trends in simulation results from multiple aircraft simulations for each system. After completion of the enhancements earlier this year, testing was also completed to exercise the six new enhanced capabilities. This section provides a description of selected tests and results from those simulation runs.

From the characterization tests for voice communications, a test case was configured to fly 122 flights, selected randomly from a standard 4800 flight, Flight Data Set. From the resulting output message data files, data was collected for specific messages that made up the message sequences for terminal/surface communication, TRACON maneuver communications and for select, en route, Center boundary-to-Center boundary messages.

Shown in Figure 1 are results of the simulation for two of the flights for the surface message sequences. For each of the two flights, the sequence of messages begins with a 'gate clearance request' message and ends with a departure TRACON, 'frequency assignment instruction acknowledge' message that occurs just before takeoff. What can be seen in these data is the message transmission sequencing, coordinated by the use of message timing data from the message scenario configuration file, and synchronized by ACES timing based on ACES NAS Agent events and decisions. In some cases for the message sequences, gaps will occur between messages due to built-in delay decisions that are a function of when a specific next-message/event will occur. An example of this is the gap between the 'ramp instruction ackmessage' and the 'taxi request message' for flight 431. These gaps are dynamic and vary in length based on ACES NAS agent decisions for sequencing of flight departures, and their function to maintain traffic flow.
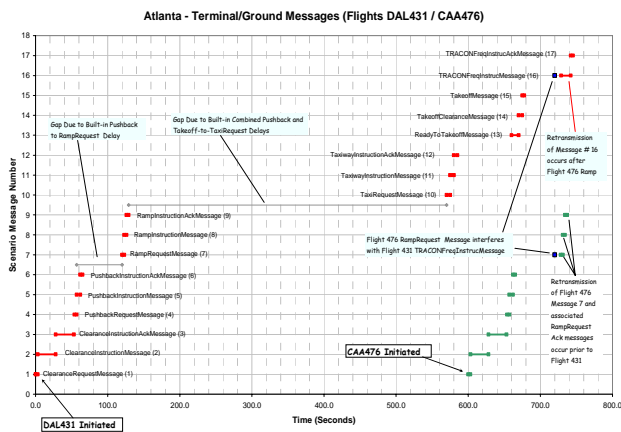

Figure 1: Surface Message Sequences (departure)

Also indicated in this chart is an instance that occurred where two messages, the flight 431 'TRACON frequency instruction' message and the flight 476 'ramp instruction message' initiate at the same time causing a radio model interference situation. For this type of message collision, the VHF communication link protocol sets the Ground to Air message as a higher priority message, and the three associated messages sequence for the ramp request are allowed to retransmit first, followed by the retransmission of the TRACON frequency instruction message. Similar type retransmissions of messages are also handled for step-on situations.

From the same voice communication simulation, Figure 2 shows results for three en-route flights passing boundary to boundary through ZOB Center. Shown in this chart are the frequency handoff instruction message sequences that routinely occur. For each flight, and preceding their entry into the Center, a new frequency has already been assigned to the flight for its use in the new center, therefore the first two messages observed after entry into the Center are a 'first contact message' sent to ATC to identify itself in the Center, and a response from ATC to acknowledge the aircraft. A similar sequence of message exchanges also occurs for each sector that each flight enters. It can be seen here that these three flights flew through one, two and three sectors and for each transition the four-message frequency handoff sequence has taken place. The final two messages for each flight are the 'frequency instruction' message from ATC and a 'frequencyassignmentacknowledgement' message from the aircraft just before entering the next Center.
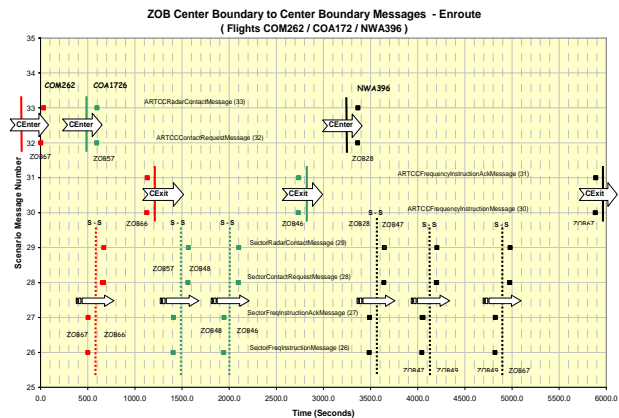

Figure 2: Center/Sector Freq. Transition Messages

From characterization testing for the VOR/DME navigation model, a simulation test case was run with 144 flights that traversed the US between several of the largest airports. From each airport, 2 identical flights were flown to each of the remaining 8 airports to be able to compare information for similar flight path data. The graph in Figure 3 is a typical plot of the results for one of the flight pairs flown between Los Angeles and Atlanta. The chart indicates the position delta (i.e. the distance between the ACES true position and the Navigation system reported position lat/lon) in nautical miles for each state message generated by the flight, gate-to-gate, for every minute.

Of interest in this plot is the pattern that can be seen (which was typical for all flight pairs) that shows a cyclical variation in the data due to the models use of the slant range in deriving a new reported position. The reason for this is that as the aircraft follows its flight path, it uses different navaid sites, to perform the reported position calculation. With the aircraft proximity to the navaid ground stations varying this has the effect of varying the accuracy of the reported position data provided by the VOR/DME model.
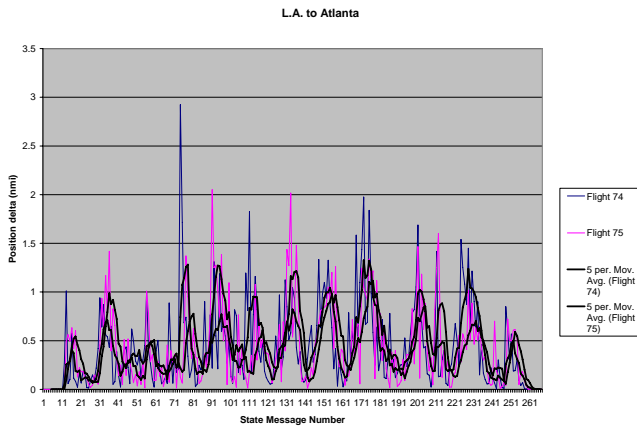
Figure 3: VOR/DME Navigation Results

In order to characterize the effect of slant range on reported position for the VOR/DME model, data was analyzed from a simulation run with a 122 flight FDS. These results are shown in Figure 4 where each column represents a 5 nm range of slant distances, with the height of the column indicating the average position difference found for each range.
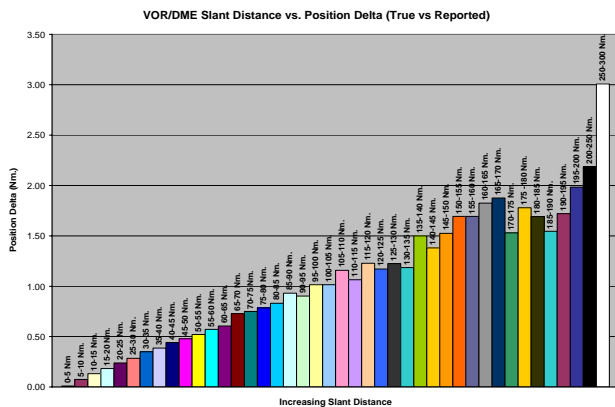

Figure 4: Slant Range vs. Reported Position Deviation

Also, from the results for the 144 flight VOR/DME model test simulation, a statistical evaluation of the data showed that the average reported position difference provided by the model is .51 nm, with a standard deviation of .692.

From Surveillance system model requirements tests, Figure 5 shows a plot of the data for three flights simulated with the 122 flight, Flight Data Set and surveillance enabled. The chart shows the difference between the ACES true aircraft position and the SSR system model, recorded position logged for these flights. Since the SSR model is a statistical model, the model simply converts the true position based on the models operation and there is no other external input that influences the result. The data for these three flights was found to be very typical of all flights in the simulation.
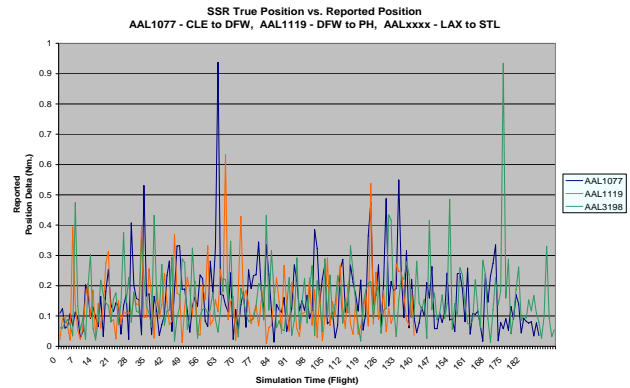
Figure 5: SSR Surveillance Results

Statistical information evaluated from the data set of all flights in this simulation found that the average variation of the reported vs. true position was .148 nm, with a standard deviation of .11.

All Flights in Simulation	
Average =	0.148127388
Variance =	0.012211818
Min =	0.000464986
Max =	1.19096608
Std Deviation =	0.110507095

Table 1: Surveillance Simulation Statistics

Enhancements - Test Results

Voice Activated Maneuvers

Two tests were run to verify operation of the Voice Activated Maneuver feature, one to set restricted regions of airspace where aircraft would need to be directed to perform a maneuver to avoid creating a flight rule restriction, and one to test an instance where an ACES CDR event directs an aircraft maneuver to avoid a flight conflict. The results of the second test are shown in Figure 6, where two flights were configured in a FDS to fly directly at each other through matching waypoints reversed in direction.

For this situation, two maneuvers were generated by ACES. Indicated in the diagram are the rerouted flight paths that each aircraft flew in the simulation, and the points at which ACES maneuvers were initiated (1,4), the points at which the communication maneuver message sequences (ATC instruction plus pilot acknowledgement) completed (2,5), and at the same time the actual start time of the aircraft maneuvers in ACES (3,6). In this instance a more dramatic maneuver can be seen being made by the northern-most flight (black aircraft), and the second maneuver is issued to the southern aircraft at a later time, possibly to complete the ACES conflict resolution.

For both ACES maneuvers in this example the time that each maneuver was delayed was 18 seconds which is the total duration of the ATC maneuver instruction and aircraft

instruction acknowledgement messages that were transmitted.
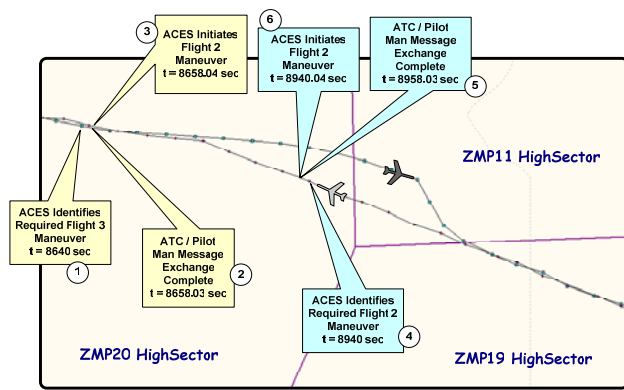

Figure 6: Voice Activated Maneuver Illustration

Short Sector Transition

To test the Short Sector transition time capability, a single flight was simulated with navigation enabled. Results from the simulation provided the flight path shown in Figure 7. From that simulation the three, circled areas in the figure were identified as the type of sector transitions that would not necessarily require ATC frequency transitions, and where frequencies of previous sectors may likely be used to cover communications through those airspace.

Based on the airspeed of the simulated aircraft (found in the FDS) and by determining the distance of the longer of the three transitions, five minutes was selected for the transition time to cover all three instances. This value was entered into the simulation and it was rerun with the short sector option enabled.
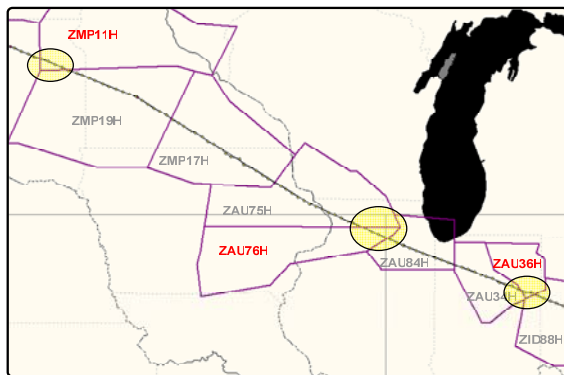

Figure 7: Short Sector Transition Illustration

The results of the simulation are shown in Table 2, with each of the frequencyIntruction message/radarContact message pairs identified in the table. These messages occur just before a sector/center crossing and just after, to initiate the frequency hand-off or confirm communication on a new frequency. As indicated in the notes on the right side of the

table, the three anticipated short regions all were skipped over in the simulation.

As an interpretation of Table 2 related to the map in Figure 7, the simulation detected that the 5 minute short sector transition time would be met for the small section of ZAU76H that the aircraft would fly through. Therefore, the frequency for the next transition that the aircraft would need to make (as it crossed into ZAU75H) was sent by the ZAU84H controller (G-A) as a ZAU75H frequency, with the controllers understanding that they would communicate with the aircraft through ZAU76H. Once the aircraft crossed over into ZAU75H, the pilot makes contact with that ZAU75H sector ATC by communicating a radarSectorContact (A-G) message to the ATC in ZAU75H.

SectorFreqInstruc	ArtccAtc.ZID	GtoA	ZID87	
	CommunicationAgent.ARTCC.ZID	GtoA	ZID87	
SectorContactRequest	Flight2	AtoG	ZID88	
	CommunicationAgent.ARTCC.ZID	AtoG	ZID88	
ARTCCFreqInstruc	ArtccAtc.ZID	GtoA	ZID88	Skips ZAU36
	CommunicationAgent.ARTCC.ZID	GtoA	ZID88	
ARTCCContactRequest	Flight2	AtoG	ZAU34	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU34	
SectorFreqInstruc	ArtccAtc.ZAU	GtoA	ZAU34	
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU34	
SectorContactRequest	Flight2	AtoG	ZAU84	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU84	
ARTCCFreqInstruc	ArtccAtc.ZAU	GtoA	ZAU84	Skips ZAU76
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU84	
ARTCCContactRequest	Flight2	AtoG	ZAU75	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU75	
SectorFreqInstruc	ArtccAtc.ZAU	GtoA	ZAU75	
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU75	
SectorContactRequest	Flight2	AtoG	ZMP17	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP17	
SectorFreqInstruc	ArtccAtc.ZMP	GtoA	ZMP17	
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP17	
SectorContactRequest	Flight2	AtoG	ZMP19	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP19	
SectorFreqInstruc	ArtccAtc.ZMP	GtoA	ZMP19	Skips ZMP11
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP19	
SectorContactRequest	Flight2	AtoG	ZMP20	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP20	
SectorFreqInstruc	ArtccAtc.ZMP	GtoA	ZMP20	
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP20	
SectorContactRequest	Flight2	AtoG	ZLC17	
	CommunicationAgent.ARTCC.ZLC	AtoG	ZLC17	

Table 2: Short Sector Transition Message Results

Navigation System Closed Loop

Since closed loop navigation operation should result in varied flight paths for an aircraft that is tracking navigation system data vs. one that is tracking ideally between waypoints, a simulation with one aircraft was used with and without this capability enabled to test its effect. For the tests one flight was flown from Dulles to Seattle, and the navigation statistics data were plotted for both flights. Results were compared to verify that tracking was occurring differently for the two cases. A section of the flight path from both flights is shown in Figure 8, with a section of that expanded to highlight a detailed region.

As can be seen in the inset, the data clearly indicate differences in the aircraft flight paths from the two simulations, which was also seen in many other instances throughout the data. Furthermore, and although we are not trying here to assess in any way the performance of this implementation as related to the ACES flight model, the results also clearly indicated that the aircraft did always return to a track that allowed the flight to meet its waypoint objectives and arrive at its destination.
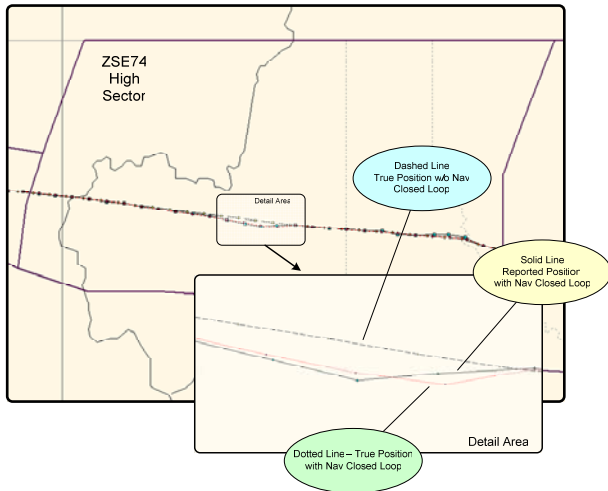

Figure 8: Navigation Closed Loop Illustration

As an additional check of the performance of closed loop, it was also believed that if this capability was operating as expected, and the aircraft were constantly adjusting flight paths to accommodate the varied reported position, that the aircraft flight times would be lengthened.

To test this, a 122 flight, simulation was run with and without closed loop enabled, and the actual flight times from the simulations were compared. For the simulation without closed loop navigation the average flight times were found to be .07 min longer than their planned flight times, and from the simulation with closed loop, flight times were found to average 6.33 min longer, which at least, in this limited test, seems to verify that the navigation system feedback was making an impact on the flight simulation results as would be expected.

NAS Concept Studies

Through the use of CNS models in ACES, analysis of NAS concepts for air traffic operations efficiencies as well as an ability to evaluate the NAS infrastructure to support them can be performed. As an example of the systems use, consider the following sample simulation and evaluation of results to provide an assessment of air traffic controller, voice communication workload in the airport/TRACON airspace for two airports.

For this example, a Flight Data Set (FDS) that identifies all of the aircraft that will fly for the simulation was built from a

standard 4800 flight FDS routinely used for testing. The FDS is comprised of flights traveling between Chicago O'Hare Airport (ORD) and Newark International (EWR) airports, and all flights that either departed from or arrived at ORD and EWR to concentrate traffic in these airports for the evaluation. The final FDS was made up of 6 flights flying from EWR to ORD, 6 flights from ORD to EWR, 104 flights departing EWR for other destinations, 87 flights arriving at EWR from other destinations, 201 flights departing from ORD to other destinations, and 229 flights arriving at ORD from other destinations. Also in constructing the flight data set, and to create a heavier traffic load than existed with the standard flight definitions, all of the flights scheduled departure times for flights departing from Chicago and Newark (317 of the 632 flights) were modified to be evenly spaced for 10 minute, Scheduled Gate Departure Time intervals which was not the case in the original file.

In order to provide more detailed output data for the voice message traffic in the specific phases of the flight that would be evaluated, the enhanced terminal frequency assignment capability was used for the simulation. In using this feature, messages are discriminated for transmission by arrival and departure and by airport surface/gate operations, airport taxiway/takeoff operations and TRACON operations. The standard TerminalConfiguration, configuration file provides this setup by default, identifying six ground stations representing six individual frequencies for messages transmitted to/from appropriate controllers (represented as separate frequencies) for these operations.

The simulation was run with voice communications enabled and was completed in approximately 20 minutes.

Since the focus of the evaluation was on the time that was required in servicing aircraft in the airport airspace and TRACON at both airports, output data was collected for the specific message sequences that occur in these airspace for both airports. For the airport airspace, this included the Gate Clearance message through the first TRACON Frequency Instruction message for departure, and the Landing Clearance Request message through the final Gate Arrival Acknowledgement message for arrival. For the TRACON airspace these included, the first TRACON Frequency Contact message through the first Center Frequency Instruction Acknowledgement message for departure, and the Approach TRACON Frequency Contact message through the Airport Frequency Instruction Acknowledgement messages for arrival. These data were sorted to include only those that were handled by the appropriate frequency assignments for ORD and EWR. The results of the assessment are shown in Tables 3 and 4.

ORD - Departures Airport Airspace			
Time Span Handling Operations: 6.85 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
1293	2.12	650	1.79

ORD - Arrival Airport Airspace			
Time Span Handling Operations: 6.12 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
496	0.59	331	0.56

ORD - Departures TRACON Airspace			
Time Span Handling Operations: 7.07 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
457	0.57	578	1.26

ORD - Arrivals TRACON Airspace			
Time Span Handling Operations: 6.18 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
705	1.51	721	1.49

Table 3: Chicago (ORD) Workload Results

EWR - Departures Airport Airspace			
Time Span Handling Operations: 4.05 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
851	1.34	386	1.04

EWR - Arrival Airport Airspace			
Time Span Handling Operations: 6.87 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
277	0.32	222	0.36

EWR - Departures TRACON Airspace			
Time Span Handling Operations: 4.24 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
536	0.65	450	0.85

EWR - Arrivals TRACON Airspace			
Time Span Handling Operations: 6.68 Hrs			
Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
433	0.93	379	0.73

Table 4: Newark (EWR) Workload Results

In the tables, five values are indicated for each of the four ORD and EWR operations. The first is the time span required to handle that operation. This value was derived by finding the timestamps for the first occurrence of the first message transmitted in the appropriate message sequence, and the final occurrence of the last message in the sequence for each airspace. This number represents the end-to-end, duration of time that would have been required to service the particular operation for the duration of the simulation. This could be viewed as the time that a controller would be sitting at a console to service the communications required for the operation category.

The remaining four values for each operations category identify a count of the voice messages that occurred, and the 'On-air' time that was required to deliver them. These are broken down by Air-Ground (combined Pilot) messages and Ground-to-Air (ATC) messages. These times therefore represent the amount of time required to communicate the messages during the span of time to service the operation, for both ATC and Pilots. These numbers also include message counts and times for any retransmitted message that were required.

Following the initial simulation, the Flight Data Set was modified again to demonstrate some of the other analysis information provided. The modification consisted of increasing the traffic load of the total simulation by doubling the number of flights departing from both the Chicago and Newark airports, and further congesting the air traffic by reducing the scheduled departure times for all of those flights (twice the number of the previous FDS) to five minute intervals. The new FDS that was created now consisted of 929 flights.

After the second simulation was run, data from several communication system statistics files were collected. Tabulated results from both simulations for message failure category data that is available are shown in Table 5. The table indicates the message failure counts for interference (i.e. congestion) failures, message step-on failures, and messages that expired (were never transmitted) after all retransmission attempts failed. Data are shown for both the original (632 flight) and the 929 flight simulation, and for occurrences within the different airspaces at each airport. As would be expected, for all channels, the instances of transmission errors show an increase. Important in this information is that the number of errors indicated for channel congestion and step-on does not necessarily indicate or translate to messages that was not delivered. Since a protocol exists in the VHF radio model for retransmission of message that incur these errors, many of these will result in a second or third attempts to transmit the message that may be successful. This would account for the low number of actual messages that expired in both simulations.

Message Failed Due to:	Airspace	632 Flight Simulation	929 Flight Simulation
Congestion	KEWR	89	316
	N90NY	297	1000
	KORD	209	299
	C90	1340	1969
Step-On	KEWR	130	200
	N90NY	126	246
	KORD	362	432
	C90	470	920
Transmission Expired	KEWR	4	4
	N90NY	5	15
	KORD	10	10
	C90	27	56

Table 5: Reported Message Error Summary

Finally from this simulation, samples of communication system results that are recorded in the output for channel availability and channel utilization are shown in Table 6 and Figure 9. For the channel availability data the information is provided for each designator used for the six frequency assignments at each airport for both sample simulations for comparison. The channel utilization plot is for the Chicago O'Hare (ORD) ground/gate departure frequency from the first sample simulation. Both are provided here to indicate the variety of data collected during a simulation and available for analysis to the user.

channelId	avg Offered Load in Erlangs	avg Offered Load in Erlangs (x2 Sim)
KORD_AG	0.43944	0.29750
KORD_AT	0.80194	0.73722
KORD_DG	3.95333	5.35777
KORD_DT	0.25972	0.34527
C90_A	3.35611	3.04277
C90_D	2.46944	4.56833
KEWR_AG	0.34055	0.30250
KEWR_AT	0.38888	0.39361
KEWR_DG	2.27611	3.00444
KEWR_DT	0.14305	0.12444
N90NY_A	1.61583	1.56055
N90NY_D	1.58333	2.63472

Table 6: ORD/EWR Arpt./TRACON Channel Availability
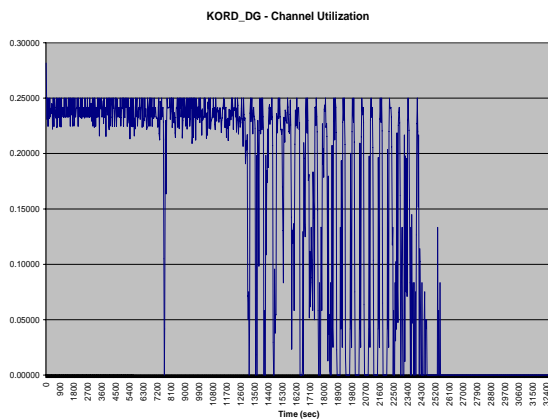
Figure 9: KORD Airport Surface Channel Utilization

Summary

ACES with CNS system models offers a diverse array of experimentation possibilities to investigate the NAS infrastructure using a proven, NAS-wide simulation tool. Testing of the recent effort to integrate the CNS modeled systems has provided very positive results. With these new modeling capabilities and their continued improvements and additions, existing concepts and new concepts that target NAS Infrastructure operations can now directly apply options to include NAS infrastructure components, and apply their results to evaluations of the concept to support their objectives.

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Communications, Navigation and Surveillance Models in ACES

Test Results and Sample Concept Simulation Results

I-CNS Conference

May 1st through 3rd, 2006

Presenter – Greg Kubat (Analex Corp.)

Authors: Greg Kubat (Analex Corp.), Don Vandrei (NASA GRC)
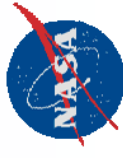
GRC Project Objectives and Teaming

Annual Project Objectives

- FY04: CNS Model Development
- FY05: Design / Integration of baseline set of CNS Models into ACES
- FY06: 1) Implement Enhanced Simulation Capabilities in ACES
       2) Design and Integration of Enhanced (2nd set) CNS Models
- FY07: Continue with CNS Model Integration / Concept evaluations

Project Team

NASA GRC - Project Management / Test and Verification

Analex Corp. - System / Model Integration Engineering

Intelligent Automation Inc. - System Design / Software Development

CNS, Inc. - CNS Model Design / Model Integration

RSIS, Inc. – Software Configuration Management
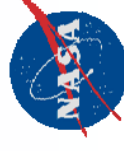
Presentation Objectives

Overview of the ACES / CNS System Models and Modeling Enhancements

Present Test Results of CNS System Modeling completed to date

Present Test Results of CNS System Modeling Enhancements completed to date

Present results of a sample Concept to demonstrate capabilities

Baseline CNS Models Description

Voice Communication with VHF Radio Model

- Simulates Voice Message Sequences for A-G (Pilot) and G-A (ATC) Voice communication
- Uses a VHF Radio, Propagation Model for simulating message transmissions
- Uses a mapped network of Ground Stations for every Airport, TRACON & Sector (L,H,S)
- Provides delay, message duration, interference determination & retransmission and Comm. Statistics as output data

VOR/DME Navigation System Model

- Simulates On-board Navigation System (Statistical model)
- Uses ACES Flight Agent, ideal state data as reference, input data
- Provides non-ideal, reported position (Lat/Long) as would be viewed by the Pilot
- Uses a mapped network of Navaid Ground Stations (FAA Data)
- Uses calculated Slant Range based on proximity to Navaid Ground Station
- Logs resulting reported position and Slant Range (distance) as output

Secondary Surveillance Radar (SSR) Surveillance System Model

- Simulated Surveillance Data transmitted to ATC (Statistical Model)
- Provides non-ideal, reported position (Lat/Long) to responsible ATC location
- Uses ACES Flight Agent, ideal state data as reference, input data
- Logs resulting non-ideal (ATC-view), reported position as output.

Voice and CPDLC Communication Messages

SIMULATED COMMUNICATION MESSAGES - TYPICAL FLIGHT

Gate-to-Gate message exchanges/message sequences derived from single flight Voice Script

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Voice Communication – Simulation Results

IAD to SEA Single Flight

Departure Gate to Takeoff

Message Sequence

from voiceScenarioDescription.csv

Description	Scenario Seq #	sequence ID	activityId	simulation Time	Message Delay (ms)	agentId	transmit Direction	nas Facility ID
FLIGHT INITIATED	1	1 / 3	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity	1116446400002 / 1116446403005	3	Flight2 / CommunicationAgent.AIRPORT.KIAD	AtoG / AtoG	KIAD / KIAD
	2	1 / 6	AirportDepartureActivity / VoiceCommunicationActivity	1116446403006 / 1116446428009	3	AirportAtc.KIAD / CommunicationAgent.AIRPORT.KIAD	GtoA / GtoA	KIAD / KIAD
				1116446428010 / 1116446453013	3	Flight2 / CommunicationAgent.AIRPORT.KIAD	AtoG / AtoG	KIAD / KIAD
	6	4 / 18	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
	7	5 / 21	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
Gate, Taxi, Takeoff Sequence	8	3 / 24	AirportDepartureActivity / VoiceCommunicationActivity				GtoA / GtoA	KIAD / KIAD
	9	6 / 27	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
	10	7 / 30	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
	11	4 / 33	AirportDepartureActivity / VoiceCommunicationActivity				GtoA / GtoA	KIAD / KIAD
	12	8 / 36	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
	13	9 / 39	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity				AtoG / AtoG	KIAD / KIAD
	14	5 / 42	AirportDepartureActivity / VoiceCommunicationActivity	1116447057004 / 1116447062007	3	AirportAtc.KIAD / CommunicationAgent.AIRPORT.KIAD	GtoA / GtoA	KIAD / KIAD
	15	10 / 45	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity	1116447062008 / 1116447065011	3	Flight2 / CommunicationAgent.AIRPORT.KIAD	AtoG / AtoG	KIAD / KIAD
	16	6 / 48	AirportDepartureActivity / VoiceCommunicationActivity	1116447114000 / 1116447117003	3	AirportAtc.KIAD / CommunicationAgent.AIRPORT.KIAD	GtoA / GtoA	KIAD / KIAD
	17	11 / 51	FlightPilotActivity.Cybele_294 / VoiceCommunicationActivity	1116447117004 / 1116447120007	3	Flight2 / CommunicationAgent.AIRPORT.KIAD	AtoG / AtoG	KIAD / KIAD

Message Sequence:

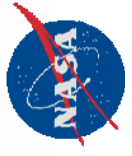| #	Message
1	ClearanceRequestMessage
2	ClearanceInstructionMessage
3	ClearanceInstructionAckMessage
4	PushBackRequestMessage
5	PushBackInstructionMessage
6	PushBackInstructionAckMessage
7	RampRequestMessage
8	RampInstructionMessage
9	RampInstructionAckMessage
10	TaxiRequestMessage
11	TaxiwayInstructionMessage
12	TaxiwayInstructionAckMessage
13	ReadyToTakeOffMessage
14	TakeOffClearanceMessage
15	TakeOffMessage
16	TRACONFrequencyInstructionMessage
17	TRACONFrequencyInstructionAckMessage

Dep TRACON Freq Instr

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Voice Communication – Simulation Results
122 Flight Simulation – Gate Depart to Takeoff Msg Sequence

Atlanta - Terminal/Ground Messages (Flights DAL431 / CAA476)

Scenario Message Number

Time (Seconds)

TRACONFreqInstrucAckMessage (17)
TRACONFreqInstrucMessage (16)
TakeoffMessage (15)
TakeoffClearanceMessage (14)
ReadyToTakeoffMessage (13)
TaxiwayInstructionAckMessage (12)
TaxiwayInstructionMessage (11)
TaxiRequestMessage (10)
RampInstructionAckMessage (9)
RampInstructionMessage (8)
RampRequestMessage (7)
PushbackInstructionAckMessage (6)
PushbackInstructionMessage (5)
PushbackRequestMessage (4)
ClearanceInstructionAckMessage (3)
ClearanceInstructionMessage (2)
ClearanceRequestMessage (1)

Retransmission of Message # 16 occurs after Flight 476 Ramp

Retransmission of Flight 476 Message 7 and associated RampRequest Ack messages occur prior to Flight 431

Flight 476 RampRequest Message interferes with Flight 431 TRACONFreqInstrucMessage

Gap Due to Built-in Combined Pushback and Takeoff-to-TaxiRequest Delays

Gap Due to Built-in Pushback to RampRequest Delay

DAL431 Initiated

CAA476 Initiated

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7

Voice Communication – Simulation Results

IAD to SEA Single Flight

Center Transition and

Sector Transition

Freq Handoff Messages

Enters 1st Center

Enters Next Sector

Description	Scenario Seq #	sequence ID	activityId	simulation Time	Message Delay (ms)	agentId	transmit Direction	nas Facility ID
Enters Dep. TRACON								
A/C Transition from Airport	18	1	FlightAscentActivity	1116447209000		Flight2	AtoG	TKIAD
		3	VoiceCommunicationActivity	1116447213001	1	CommunicationAgent.TRACON.TKIAD	AtoG	TKIAD
	19	1	TerminalDepartureActivity	1116447213002		TraconAtc.TKIAD	GtoA	TKIAD
			VoiceCommunicationActivity	1116447227003	1	CommunicationAgent.TRACON.TKIAD	GtoA	TKIAD
				1116447227004		Flight2	AtoG	TKIAD
				1116447232005	1	CommunicationAgent.TRACON.TKIAD	AtoG	TKIAD
				1116447397260		TraconAtc.TKIAD		
Messages		21	VoiceCommunicationActivity	18		DepartureTRACONContactRequestMessage …ON.TKIAD	GtoA	TKIAD
		4	TerminalDepartureActivity	19		DepartureTRACONRadarContactWithInstructionMessage …ON.TKIAD	AtoG	TKIAD
		24	VoiceCommunicationActivity	20		DepartureTRACONRadarContactWithInstructionAckMessage …ON.TKIAD	GtoA	TKIAD
	64	5	FlightAscentActivity	64		DepartureManeuverMessage	GtoA	TKIAD
		27	VoiceCommunicationActivity	65		DepartureManeuverAckMessage …ON.TKIAD	AtoG	TKIAD
	65			21		FirstARTCCFrequencyInstructionMessage …ON.TKIAD	GtoA	TKIAD
				22		FirstARTCCFrequencyInstructionAckMessage …ON.TKIAD	AtoG	TKIAD
A/C transition from Departure Center into first Center (ie ZDC Enroute Airspace)	21	5	TerminalDepartureActivity	23		FirstARTCCContactRequestMessage …ON.TKIAD	GtoA	TKIAD
		30	VoiceCommunicationActivity	24		ARTCCRadarContactWithInstructionMessage …ON.TKIAD	AtoG	TKIAD
	22	6	FlightAscentActivity	25		ARTCCRadarContactWithInstructionAckMessage …ON.TKIAD	AtoG	TKIAD
			VoiceCommunicationActivity					
	23	2	FlightEnRouteActivity	26		SectorFrequencyInstructionMessage …CC.ZDC	AtoG	ZDC05
		3	VoiceCommunicationActivity	27		SectorFrequencyInstructionAckMessage	AtoG	ZDC05
	24	1	CrossingActivity.ZDC	1116448053784		ArtccAtc.ZDC	GtoA	ZDC05
		6	VoiceCommunicationActivity	28		SectorContactRequestMessage …CC.ZDC	GtoA	ZDC05
	25	3	FlightEnRouteActivity	29		SectorRadarContactMessage	AtoG	ZDC05
		9	VoiceCommunicationActivity	1116448064787	1	CommunicationAgent.ARTCC.ZDC	AtoG	ZDC05
Sector to Sector	26-1	2	CrossingActivity.ZDC	1116448218782		ArtccAtc.ZDC	GtoA	ZDC05
		72	VoiceCommunicationActivity	1116448221783	1	CommunicationAgent.ARTCC.ZDC	GtoA	ZDC05
	27-1	4	FlightEnRouteActivity	1116448221784		Flight2	AtoG	ZDC05
		75	VoiceCommunicationActivity	1116448224785	1	CommunicationAgent.ARTCC.ZDC	AtoG	ZDC05
	28-?	83	FlightEnRouteActivity	1116448373782		Flight2	AtoG	ZDC03
		83	VoiceCommunicationActivity	1116448378783	1	CommunicationAgent.ARTCC.ZDC	AtoG	ZDC03
	29-1	3	CrossingActivity.ZDC	1116448378784		ArtccAtc.ZDC	GtoA	ZDC03
		87	VoiceCommunicationActivity	1116448381785	1	CommunicationAgent.ARTCC.ZDC	GtoA	ZDC03

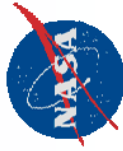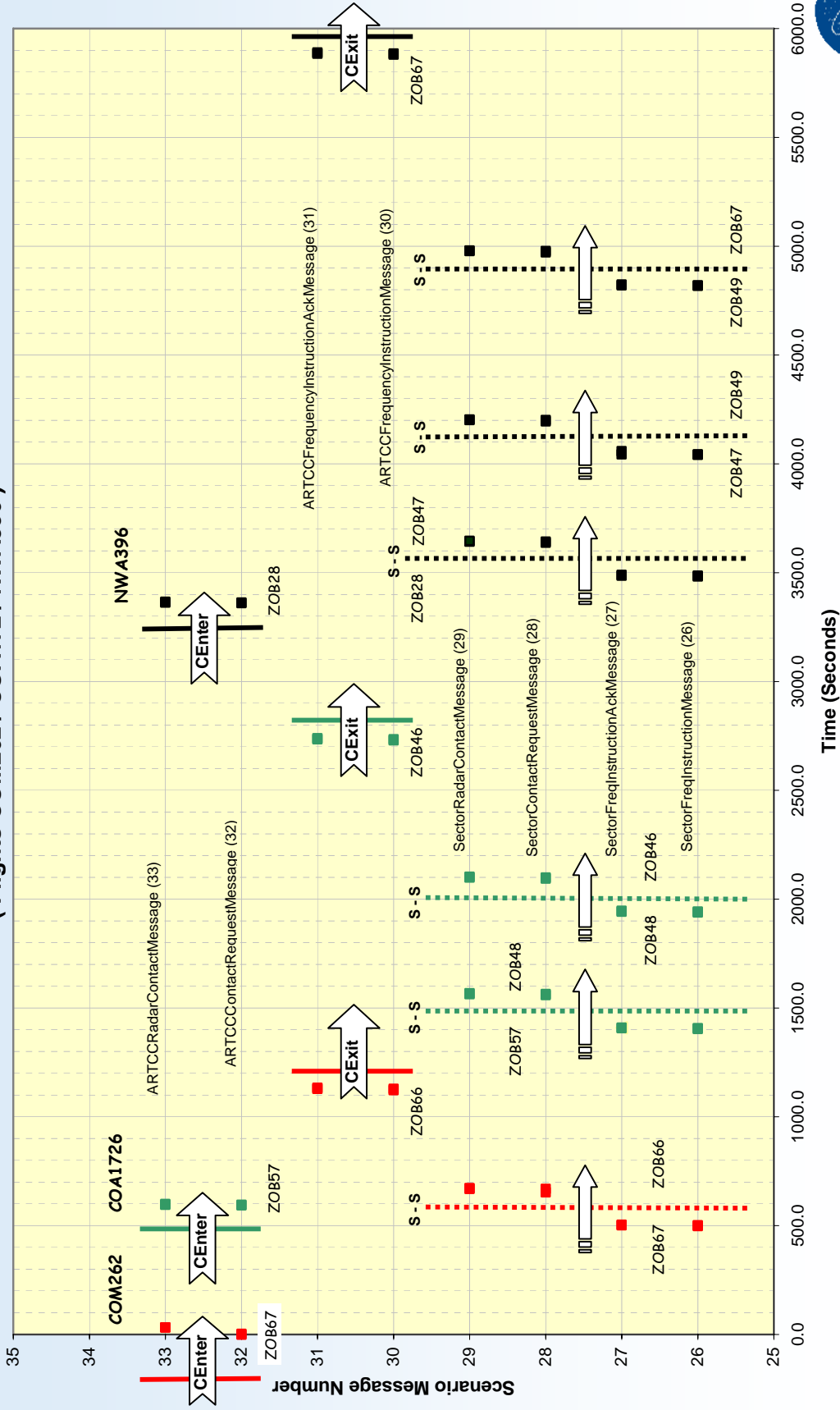Glenn Research Center at Lewis Field
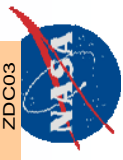
Voice Communication – Simulation Results

122 Flight Simulation – Center and Sector Frequency Handoff Msg Sequences

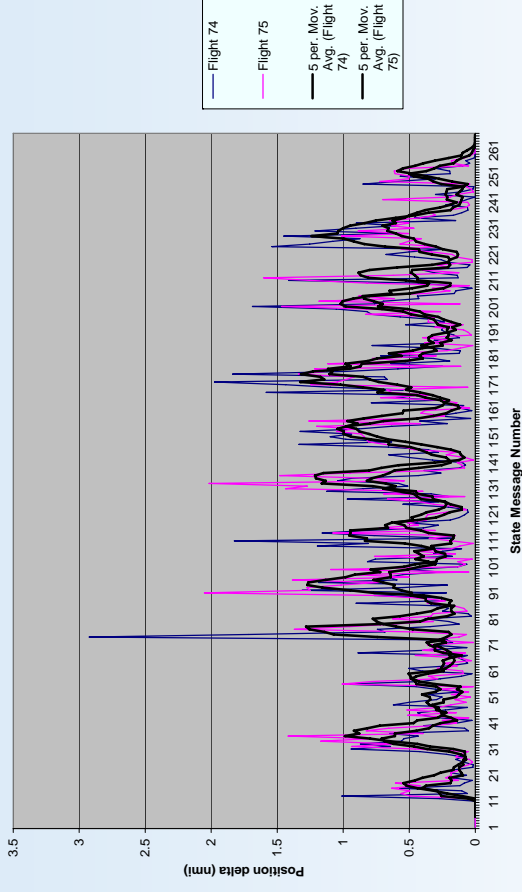### ZOB Center Boundary to Center Boundary Messages - Enroute
(Flights COM262 / COA172 / NWA396)

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Navigation (VOR/DME) Characterization Test Results

L.A. to Atlanta

- **Test simulation flew two flights along same routes between several major US airports.**

- **Typical resulting plot showing difference between true and reported position (i.e. position delta) for each Flight Agent State message (1/min)**

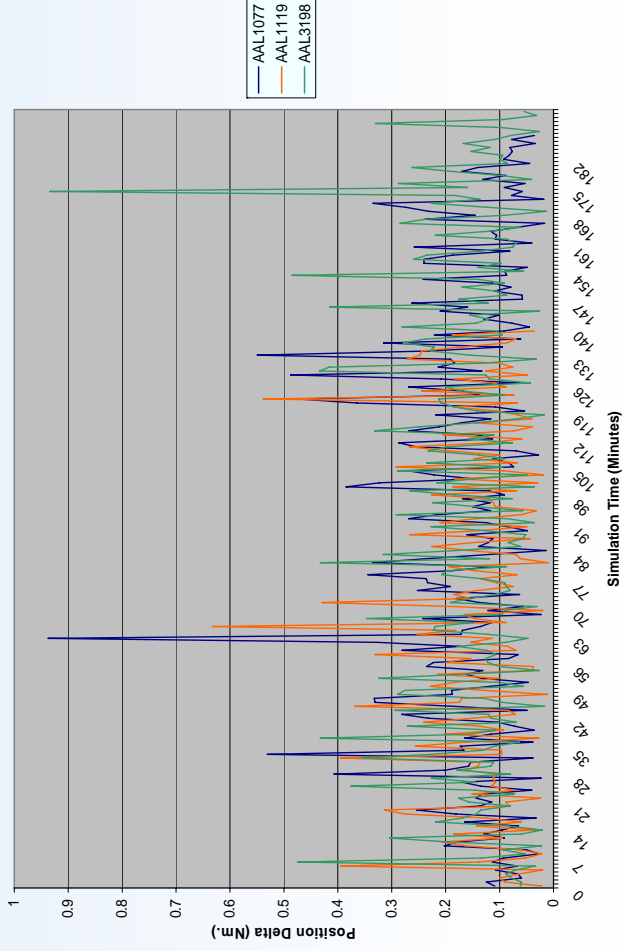- **Cyclical pattern in all plots due to Slant Range value effect on model accuracy**
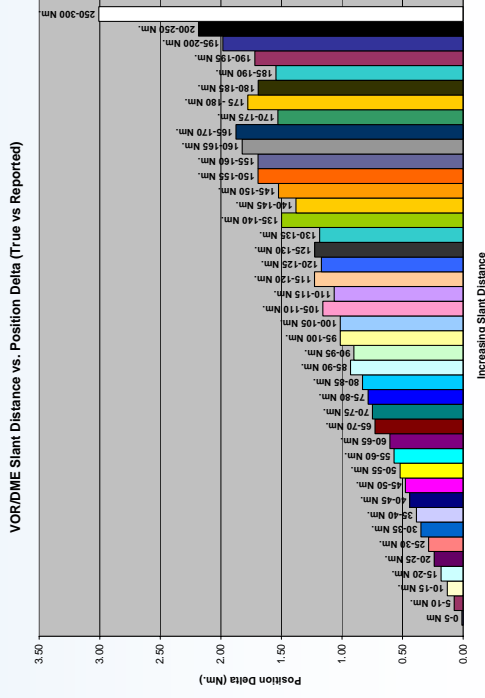
- **Lower chart from 122 flight simulation**

- **Indicates ranges of Slant Range vs. Position delta (larger slant distance – wider position difference)**

- **Avg delta = .51 nm   StdDev =.692**

Surveillance (SSR) Characterization Test Results

- **Used 122 Flight Simulation for Testing**

- **Chart shows difference in ACES Flight model, true position and Surveillance Model reported position (i.e position delta) vs. Sim. time in minutes for each State message generated (1/min) – from 3 flights**

- **Typical results for all flights.   Avg Delta = .148 nm   StdDev = .11**

All Flights in Simulation	
Average =	0.148127388
Variance =	0.012211818
Min =	0.000464986
Max =	1.19096608
Std Deviation =	0.110507095

SSR Reported Position vs. True Position
AAL1077 - CLE to DFW, AAL1119 - DFW to PHX,   AAL3198 - LAX to STL

Legend: AAL1077, AAL1119, AAL3198

Y-axis: Position Delta (Nm.)
X-axis: Simulation Time (Minutes)

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Enhanced Capabilities Description

Voice Activated Maneuvers

- NAS Conflict Detection and Resolution and Airspace/Region restriction conditions use rerouting messages to initiate varied flight path or flight dynamics

Short Sector Transition Time (Freq Handoff Messages)

- Reduces number of freq handoff message sequences by providing short sector transit time.
- Variable transit time setting as a parameter to skip new frequency assignment decisions.
- Influences the total number of communication messages transmitted to the aircraft.

Enhanced Terminal Frequency Assignments

- Aircraft operations in the terminal airspace rely on a flexible communications system to handle traffic volume and differentiate operations to all aircraft.
- Number of voice communication frequencies increased by providing an improved distribution of GS/channel assignments for selected airports.
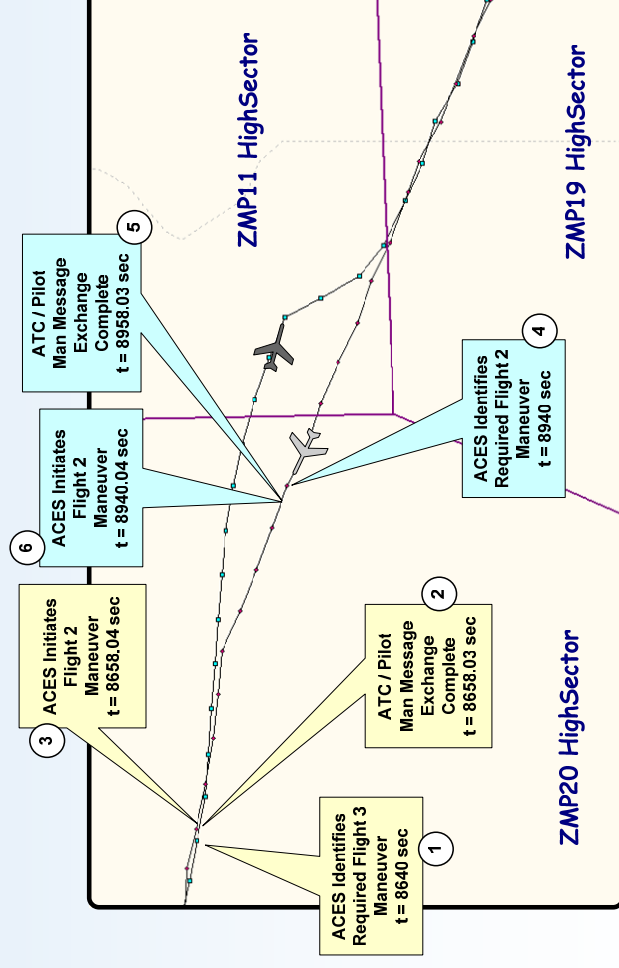
Navigation – Closed Loop Operation

- Navigation systems provide position information to Aircraft
- Used real-time for steering of the aircraft as either pilot or Auto-pilot
- CL allows the accuracy of navigation system information to impact flight dynamics.

Surveillance – Closed Loop Operation

- Surveillance systems provide position information to Air Traffic Controllers
- Surveillance information is used real-time for ATC operations and decision making.
- CL allows accuracy of surveillance system models to be reflected into ATC operations and decision making.

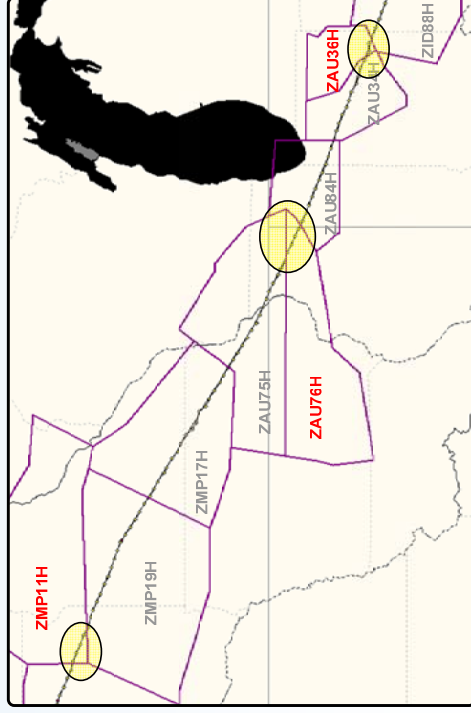# Communication Activated Maneuvers Enhancement – Results

- Two flights simulated between Seattle and Dulles Airports flying opposite directions.
- Flight paths reversed by inverting waypoints in Flight Data Set – Head on.

➢ Graphic shows results of ACES Maneuver(s) that occurred after 18 sec delay to deliver A-G Instruction and G-A Instruction Acknowledgement Voice messages.

➢ ACES generated two maneuvers. Both were initiated following voice message transmissions.

ZMP11 HighSector

ZMP19 HighSector

ZMP20 HighSector

5 — ATC / Pilot Man Message Exchange Complete t = 8958.03 sec

6 — ACES Initiates Flight 2 Maneuver t = 8940.04 sec

4 — ACES Identifies Required Flight 2 Maneuver t = 8940 sec

3 — ACES Initiates Flight 2 Maneuver t = 8658.04 sec

2 — ATC / Pilot Man Message Exchange Complete t = 8658.03 sec

1 — ACES Identifies Required Flight 3 Maneuver t = 8640 sec

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Short Sector Transition Time Enhancement – Results

- Flew a Single flight Sim to determine where the aircraft flew over short segments of Sectors (ZAU36, ZAU76 and ZMP11)
  - Determined distance of longest segment
  - Determined flight time based on A/C airspeed
  - Set Transition Time = 5 min in simulation
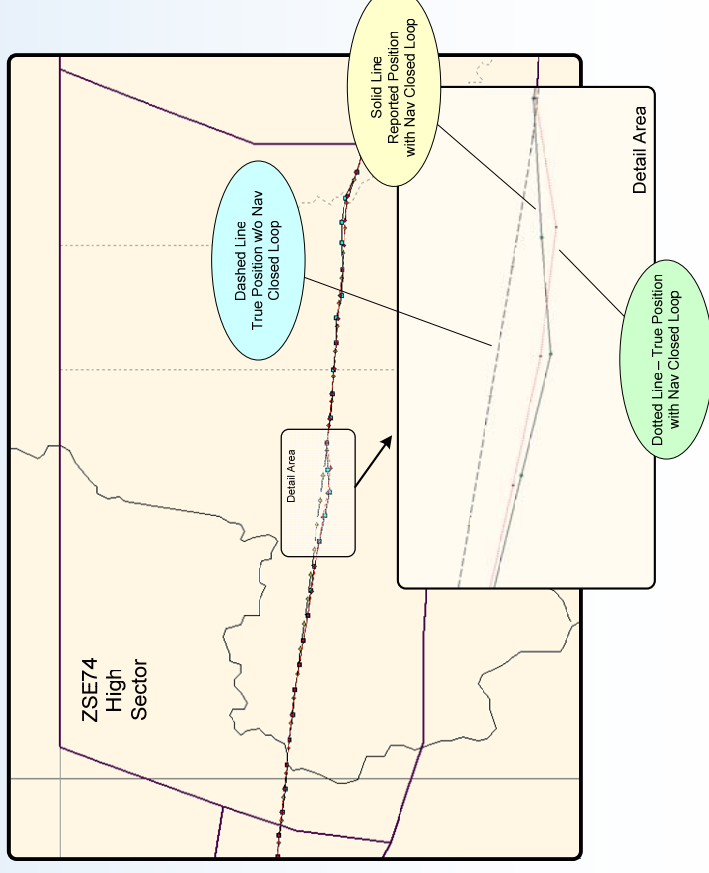 - Collected data for Center and Sector freq handoff messages

➢ Table shows that frequency handoffs occur for Center and Sector Transitions beyond the short segments. (for example: ZAU84 to ZAU75 instead of ZAU84 to ZAU76)

Message	Agent	Direction	Code	Note
SectorFreqInstruc	ArtcAtc.ZID	GtoA	ZID87	
	CommunicationAgent.ARTCC.ZID	GtoA	ZID87	
SectorContactRequest	Flight2	AtoG	ZID88	
	CommunicationAgent.ARTCC.ZID	AtoG	ZID88	
ARTCCFreqInstruc	ArtcAtc.ZID	GtoA	ZID88	Skips ZAU36
	CommunicationAgent.ARTCC.ZID	GtoA	ZID88	
ARTCCContactRequest	Flight2	AtoG	ZAU34	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU34	
SectorFreqInstruc	ArtcAtc.ZAU	GtoA	ZAU34	
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU34	
SectorContactRequest	Flight2	AtoG	ZAU84	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU84	
ARTCCFreqInstruc	ArtcAtc.ZAU	GtoA	ZAU84	Skips ZAU76
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU84	
ARTCCContactRequest	Flight2	AtoG	ZAU75	
	CommunicationAgent.ARTCC.ZAU	AtoG	ZAU75	
SectorFreqInstruc	ArtcAtc.ZAU	GtoA	ZAU75	
	CommunicationAgent.ARTCC.ZAU	GtoA	ZAU75	
SectorContactRequest	Flight2	AtoG	ZMP17	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP17	
SectorFreqInstruc	ArtcAtc.ZMP	GtoA	ZMP17	
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP17	
SectorContactRequest	Flight2	AtoG	ZMP19	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP19	
SectorFreqInstruc	ArtcAtc.ZMP	GtoA	ZMP19	Skips ZMP11
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP19	
SectorContactRequest	Flight2	AtoG	ZMP20	
	CommunicationAgent.ARTCC.ZMP	AtoG	ZMP20	
SectorFreqInstruc	ArtcAtc.ZMP	GtoA	ZMP20	
	CommunicationAgent.ARTCC.ZMP	GtoA	ZMP20	
SectorContactRequest	Flight2	AtoG	ZLC17	
	CommunicationAgent.ARTCC.ZLC	AtoG	ZLC17	

Map labels: ZMP11H, ZMP19H, ZMP17H, ZAU75H, ZAU76H, ZAU84H, ZAU36H, ZID88H, ZLC17

Navigation Closed Loop Enhancement – Results

- Simulated a single flight with VOR/DME enabled and with/without Closed Loop Navigation enabled to determine the effect on the anticipated variation in flight path.
  - Several deviations from ACES flight path were observed. (shown in detail view below)
  - Aircraft returned to planned waypoints – control loop seems functional
- From Simulation with 122 flight, FDS (testing to see if flight durations lengthened)
  - Average flight durations increased by 6.2 minutes

ZSE74 High Sector

Detail Area

Dashed Line True Position w/o Nav Closed Loop

Solid Line Reported Position with Nav Closed Loop

Dotted Line – True Position with Nav Closed Loop

Detail Area

New CNS Models Description (FY06)

CPDLC (Data link) Communication with VDL-2 Radio Model

- Simulates CPDLC digital messages mapped to Voice model message sequences
- Digital messages derived from CPDLC Baseline 1 and 2, & RTCA DO-269
- Uses a VDL-2 Radio Model for simulating message transmissions
- Uses a (user configurable) mapped network of Ground Stations
- Provides delay, interference determination, retransmission and Comm. Statistics as output data

GPS Navigation System Model

- Simulates On-board GPS Navigation System (Statistical model - LAAS /WAAS)
- Uses ACES Flight Agent, ideal state data as reference, input data
- Provides non-ideal, reported position (Lat/Long) as would be viewed by the Pilot
- Logs resulting reported position and Slant angle/range (distance) as output

Automatic Dependent Surveillance – Broadcast Surveillance System Model

- Simulated as Onboard system – Transmits Nav model results + Flight State data in each message (Lat/Long, Heading, Altitude, speed, etc)
- Uses Mode S Radio model for simulating message transmissions
- Mode S model determines message delivery success/failure probability + interference
- Additional Mode S system data carried over same link (TCAS, SSR)
- Simulates delivery of ADS-B Data to responsible ATC location
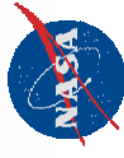- Logs data as output

Airport/TRACON ATC Workload – Sample Concept/Results

Objective: Determine ATC On-Air, communication Workload for Airport Airspace Operations for a relatively heavy load of aircraft traffic for ORD and EWR.

- 632 flight FDS w/ air Traffic focused on Arrivals and Departures at ORD and EWR
- ORD and EWR Departures (317 flights) spaced at 10 min departure intervals
- Voice Communications enabled, Terminal Freq Assign. Enhancement enabled

➢ Retrieved message sequences – Gate thru TRACON for departures, TRACON to Gate for arrival at both airports.

➢ Separated A-G message types as ATC, and G-A message types as Pilot messages (by freq)

➢ Totaled messages w/retransmitted messages. Totaled durations, delays for each group

ORD - Departures Airport Airspace
Time Span Handling Operations: 6.85 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
1283	2.12	650	1.79

ORD - Arrival Airport Airspace
Time Span Handling Operations: 6.12 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
496	0.59	331	0.56

ORD - Departures TRACON Airspace
Time Span Handling Operations: 7.07 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
457	0.57	578	1.26

ORD - Arrivals TRACON Airspace
Time Span Handling Operations: 6.18 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
705	1.51	721	1.49

EWR - Departures Airport Airspace
Time Span Handling Operations: 4.05 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
851	1.34	386	1.04

EWR - Arrival Airport Airspace
Time Span Handling Operations: 6.87 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
277	0.32	222	0.36

EWR - Departures TRACON Airspace
Time Span Handling Operations: 4.24 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
536	0.65	450	0.85

EWR - Arrivals TRACON Airspace
Time Span Handling Operations: 6.68 Hrs

Total # of A-G messages	(A-G) Pilot Combined On-Air Time (Hrs)	Total # of G-A messages	(G-A) ATC On-Air Time (Hrs)
433	0.93	379	0.73

Airport/TRACON ATC Workload - Sample Concept Results

Increased the FDS air traffic by doubling the number of Departing flights from ORD and EWR to evaluate the effect on communication message Interference and Step-on occurrences. (929 flights)

- **Set the departure times to 5 min spacing for all flights departing ORD and EWR**

➢ **Recorded the number of Congestion (Interference) Errors, Step-on Errors and Expired Transmissions (I.e. messages never sent)**

➢ **Compared data for 632 and 929 flight simulation**

Message Failed Due to:	Airspace	632 Flight Simulation	929 Flight Simulation
Congestion	KEWR	89	316
	N90NY	297	1000
	KORD	209	299
	C90	1340	1969
Step-On	KEWR	130	200
	N90NY	126	246
	KORD	362	432
	C90	470	920
Transmission Expired	KEWR	4	4
	N90NY	5	15
	KORD	10	10
	C90	27	56

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# Airport/TRACON ATC Workload - Sample Concept Communication System Data

- **Examples of Communications Statistics information stored from each Communications Simulation**

**Channel availability table shows data from 632 flight vs. 929 flight (x2) Sim**

Channel utilization plot obtained from 632 flight simulation. (Data for KORD departure Gate/Ramp/Taxiway)

KORD_DG - Channel Utilization

Channel Utilization Data

channelId	avg Offered Load in Erlangs	avg Offered Load in Erlangs (x2 Sim)
KORD_AG	0.43944	0.29750
KORD_AT	0.80194	0.73722
KORD_DG	3.95333	5.35777
KORD_DT	0.25972	0.34527
C90_A	3.35611	3.04277
C90_D	2.46944	4.56833
KEWR_AG	0.34055	0.30250
KEWR_AT	0.38888	0.39361
KEWR_DG	2.27611	3.00444
KEWR_DT	0.14305	0.12444
N90NY_A	1.61583	1.56055
N90NY_D	1.58333	2.63472

Channel Availability Statistics

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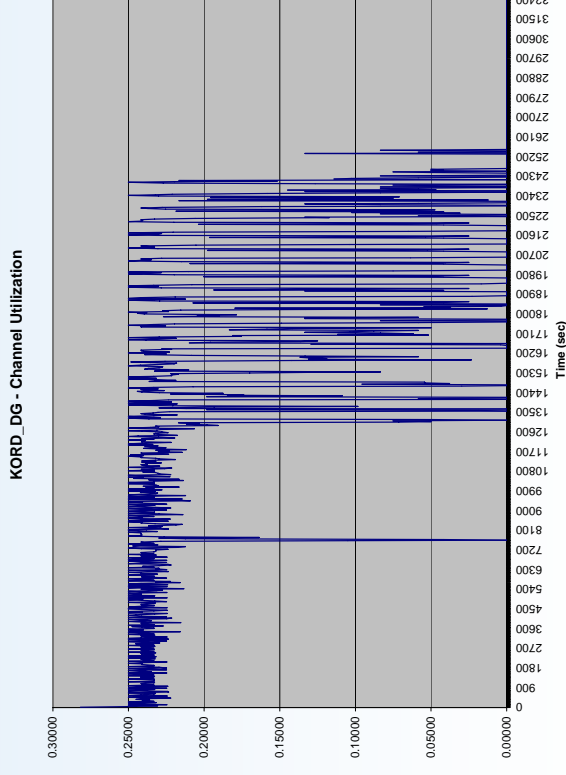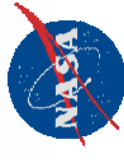
ACES with CNS Models – Potential Improvements

ACES with CNS Models Additions / Improvements

- Perform verification of results and investigate increasing the fidelity of Models as needed
- Investigate accuracy of message counts and adjust for more realistic results as needed.
- Add UAT Communication Model for ADS-B
- Add Aircraft-to-Aircraft ADS-B implementation (Currently A-G only)
- Add TIS-B and FIS-B System Models that use UAT as the data link
- Opportunity to exercise the system more (run more simulations) to determine required improvements
- Opportunity to build analysis applications to help with compiling data and simulation evaluations

ACES Additions / Improvements (we would like to have had)

- More frequent flight model state message updates (used as reference for CNS Models)
- Addition of ACES maneuver capability in the Airport/TRACON airspace.

ACES with CNS Models – Summary

ACES with CNS Models offers a wide array of experimentation possibilities

Provides an Opportunity to investigate NAS CNS infrastructure operations or CNS technology comparisons in a proven NAS simulation environment (ACES)

Concept studies could simultaneously obtain results directed at CNS system issues that could determine success or failure of a concepts implementation.