Title: Communication, Navigation and Surveillance Models in ACES for Concept Developers

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Abstract: Agent-based software simulation infrastructures have become a key technology for modeling and simulation of the National Airspace (NAS). NASA's Airspace Concept Evaluation System (ACES), is one such example. In ACES, flights and NAS entities such as Airports, TRACONs, ATC, ARTCC's and Traffic Flow Management (TFM) systems, etc. are modeled as a set of dynamic interacting agents capable of simulating Gate-to-Gate NAS operations. ACES focuses on simulations of physical entities of the NAS, providing a tool for Concept Developers to investigate and analyze advanced concepts to improve airspace utilization and safety under various conditions. However, with any new concept that is studied, its success in meeting its objectives needs to take into account all critical NAS support elements including the inherent use of current and/or new technology CNS systems. With these systems added to concept analysis, any CNS system limitations or improvements that could be realized would be able to be identified in parallel with the concept study, since CNS systems will be intricately tied to all NAS operations. Without this capability for example, users may wrongfully conclude that terminal airspace capacity can be increased using a new physical concept, without an indication that the increased capacity cannot be sustained by the current Communication system, and alternatives would be required. Therefore it is worthwhile for the users to be able to evaluate capacity versus safety with CNS systems analysis included, which would add to the substance and credibility of any cost-benefit analysis performed to support the concept.

To provide extended capabilities to ACES users, several CNS models have been developed and integrated with ACES. The paper is organized into three primary sections. The first section presents a brief overview of Communication system modeling of VHF/ Voice and VDL-2/CPDLC based pilot-controller communication, Navigation system modeling of VOR/DME and LAAS/WAAS-GPS used by the flights, and Surveillance system modeling of SSR and ADS-B used by Air Traffic Control. These models are developed as Cybele Agents and Activities similar to the NAS models in ACES. The second section describes how concept developers are now able to configure characteristics of different CNS models, apply those specific models to different regions and flights, and thus be able to evaluate a new NAS concept using those models. The third describes the critical indicators such as communication delays, channel utilization, flight trajectory deviation, workload, and safety that can be directly or indirectly derived from the output. These indicators can then be used to justify whether the modeled CNS system can sustain improvements to capacity resulting from the new concept.

Introduction

As the US, National Airspace System approaches the timeframe predicted at the turn of the century where air traffic capacity and therefore air safety will begin to reach critical dimensions, many new technology CNS systems to improve, and even automate, air traffic management and aid in lessening the workload of Air traffic controllers are now in later phases of design, and first phases of deployment. As these systems have developed, there has also been an ongoing effort to develop CNS system infrastructure architectures and fuse these technologies into a cohesive system that takes best advantage of the benefits that each/all will provide. This effort will rely on research and analysis tools that can provide information to evaluate sound concepts.

ACES, as a tool developed to provide NAS-wide, Airspace concept evaluations, has proven effective to concept developers for just this type of evaluation. To date, several concepts have found ACES simulation capabilities valuable in supporting analysis for the study of aircraft surface movement efficiencies and aircraft routing concepts that may be considered in future system implementations. However, not until September 2005 did ACES have available CNS system models and simulation capabilities to provide a link between physical NAS operations and CNS technology applications to further its usefulness to help develop CNS system infrastructures to support those concepts.

The following is a description of the general design of ACES CNS Modeling implementation developed at NASA, Glenn Research Center as a baseline system. The design approach is explained and examples of how the approach is applied are presented. Information is provided to describe the ACES/CNS modeling configuration capabilities. Also, information is provided to identify CNS application models that are currently in development and enhancements to baseline modeling capabilities to meet the FY06 deliverables. Finally, examples are presented to indicate the potential use of the system for concept evaluations.

ACES/CNS Model Implementation

As its core development environment, ACES uses CybelePro™, which is an Agent-based programming framework that utilizes autonomous, interactive software components, referred to as *Agents*. Agents in ACES can communicate with other agents where information is shared, states can be monitored, tasks can be delegated, and activities can be coordinated. ACES Agents are programmed to perform different types of *activities* in the context of the NAS domain. Examples of ACES Agents that represent NAS participants and operations include: Air

Traffic Control (ATC), Traffic Flow Management (TFM), Aircraft (as flight Agents), en route Air Route Traffic Control Centers (ARTCC) and Terminal Radar Approach Control (TRACON). With this agent based framework utilizing *activities* as core components and a publish/subscribe paradigm for distributing information, the ACES infrastructure simulates all NAS functions and provides access to ACES messages and events that are used as input to CNS model operations.

The integration of CNS system models in ACES leverages this Agent based framework. The design incorporates Communication, Navigation and Surveillance Agents that provide containers for multiple, similar-model-type *activities*. Models for radios and their related, functional communication medium characteristics used for all systems that required transfer of information are contained in the Communication Agent, whereas statistical Navigation models and Surveillance models and/or their associated functional components are implemented as activities of their respective Agents. In a simulation, these agents are distributed in the simulation (i.e. NAS) environment to provide their respective operations where needed for transmitting or receiving ACES or communication system messages to models using the publish-subscribe paradigm.

The following section identifies the design of the CNS models that was employed using the features of the Agent based, CybelePro environment in ACES.

ACES CNS Model Implementation – Design Approach

To integrate CNS models in ACES, the design approach focused on developing a modular framework to take advantage of the ACES, CybelePro Agent-Activity/publish-subscribe environment to successfully provide flexibility for integration of the variety of CNS systems that could be introduced. With such an approach, once basic elements for CNS models were established, new CNS technology models could be easily adapted using similar functionality. Also, once models were integrated, a user would have multiple models available simultaneously to run simulations using similar application types to operate modeled CNS systems in parallel for comparison, or with two or more models in tandem for the study of more complex concepts. The diagram in Figure 1 shows an example of the resulting design as illustrated by the Communication Agent.

As shown, the Communication Agent effectively forms a container (Communication Agent) for various communication radio/medium models, each functioning independently as communication Agent Activities. In its operation, a sender Agent of a communication system message (Flight or ATC Agent) publishes a communication message, which is subscribed to by an upgraded ACES Communication Service, CNS forwarder. When the CNS forwarder receives a communication message, the forwarder interprets the message type for its intended communication model. With that information, the forwarder applies a new tag for delivery to that model, and wraps the original message information in a new header for later delivery to the intended receiver (Flight or ATC Agent) activity.

When the communication model Activity receives the message, the model processes the message applying radio characteristics, channel interference and loading, retransmission protocols, and any relevant physical attributes such as ground station proximity and vicinity of other aircraft as interferers that the model requires. After the communication model message processing is complete, the communication model/Activity then publishes the message again to the intended receiver agent as its final destination, and message transmission characteristics are logged for later use for each message.

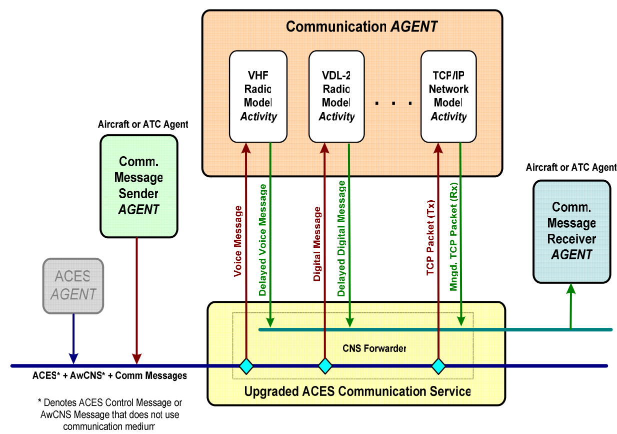

Figure 1: Communications System Modeling

With similar operation to the Communications Agent, a Surveillance Agent was also introduced to implement surveillance system models using a similar method for transferring information. However, for the surveillance, this required that the CNS forwarder subscribe to ACES true aircraft state messages (as reference information) published as surveillance messages from the ACES flight physics model. When the CNS forwarder detects these messages, it again wraps the destination message information with a surveillance model header and publishes the message to an appropriate surveillance model. The model receives the message information, acts on the data and republishes the processed state data it to its final destination. Since surveillance systems results are ultimately used by air traffic control, an ATC Agent is assumed as the final receiver destination for all surveillance system model data. Therefore surveillance models also simulate information processing that occurs in the system as viewed at the ATC end user display. The data for each processed surveillance message is also logged for later use. A diagram of the surveillance model structure is shown in Figure 2.

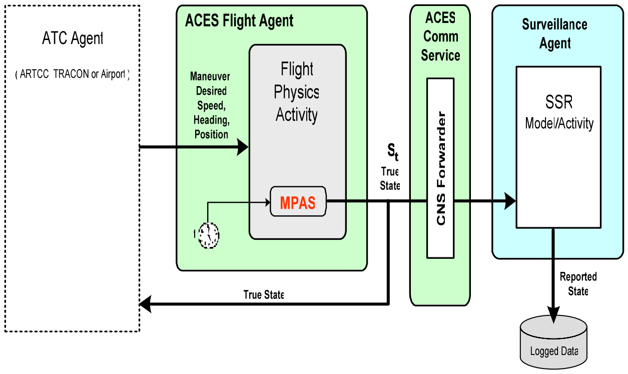

Figure 2: Surveillance Systems Modeling Design

For Navigation models, since navigation systems are physically located onboard aircraft and since the reference information (i.e. aircraft state data) such as latitude, longitude, heading, etc… required by these models is available from the ACES flight physics model, these models are implemented as Activities of the existing ACES Flight Agent. The flight Agent provides updates of the state information at a rate of once per minute and therefore the navigation models are able to provide new position data as seen by the pilot at that rate. A general depiction of the Navigation model is shown in Figure 3. Output data from navigation models is logged to ACES output files for use at a later time.

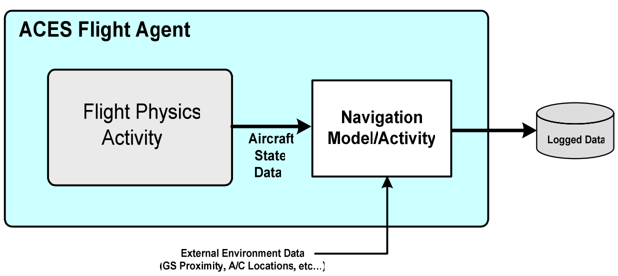

Figure 3: Navigation Systems Modeling Design

Design Flexibility

In applying the above described design for each of the three system types, standardized modifications to the system are possible for integrating new models. In introducing a model to the system, a model only requires that either the model (or new activities to support the modeled system) subscribe to ACES messages as needed as independent activities, or that the CNS forwarder be updated to perform a new subscribe-wrap-publish operation. Also, with similar application type models (i.e. C, N or S), which typically require similar external data, the approach provides established initialization processes and configuration files to provide information to the new model, at the model level, with minimal added ACES overhead.

As an example of the flexibility of the system, consider the recent design implementation of ADS-B as a new system model for the FY06 deliverable (Figure 4). Although this surveillance system model is one of the more complex to be implemented, much of the integration followed the same methods that were used for the baseline models to integrate the end-to-end system model, greatly simplifying the design effort.

With ADS-B, the surveillance system is no longer a ground-based system that senses aircraft and only requires aircraft state data as reference information. With ADS-B, the system relies on navigation (and other) systems onboard the aircraft for data, and uses a communication link to transmit this data to nearby aircraft[1] and ground stations for processing and eventual transfer to ATC. Therefore to implement this model required adding ADS-B model components, a Communication link model, use of existing navigation model output data and use of the CNS Forwarder for directing appropriate messages. Figure 4 illustrates the ADS-B system model design.

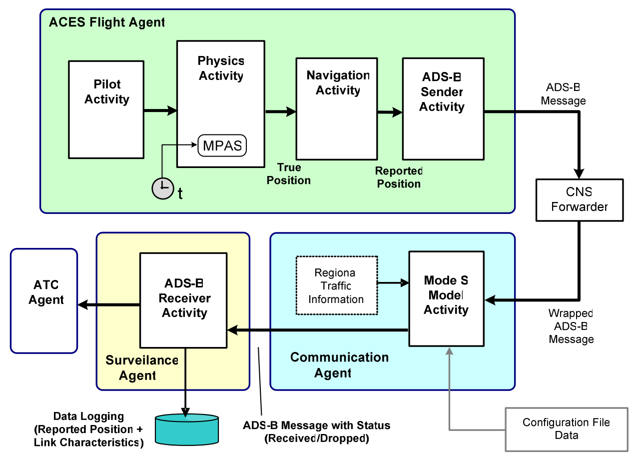

Figure 4: ADSB System Model

For the ADS-B model components, an ADS-B sender Activity was added as an Activity of the Flight Agent, and a receiver Activity was added to the Surveillance Agent. By locating the sender Activity within the Flight Agent, the design reflects an ADS-B system onboard the aircraft in a similar manner to what would occur in a real system and allows the simulation to be handled by appropriate ACES components. Each flight generates ADS-B message packets containing reported position from the Navigation model selected for the simulation, and other state data that provides physical information about the aircraft. Once the Sender activity receives new data, its published message is delivered to the Comm. model as a wrapped ADS-B message by the CNS Forwarder for processing. Message packets processed by the communication model are

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[1] This implementation of simulated ADS-B transmits only to ground stations.

simulated as to be in the form of a standard size digital ADS-B message.

For the Communication Model, the ADS-B system model uses Mode S as its data link and therefore a new Mode S Radio model was developed and added to the Communication Agent. In adding that model, many of the same type of required model input/configuration data had already been used by the VHF radio model developed for the baseline Voice communication system. Therefore information required by the Mode S model for initialization and configuration were added as needed to already established configuration files.

The receiver Activity was added as an activity of the Surveillance Agent and is responsible for receiving and if needed for directing ADS-B reported position, state data and link characteristics for logging of the messages and for directing data to other ATC Agents.

For operation of the end-to-end system, the Flight Agent, ADS-B sender Activity publishes an ADS-B message for every update of the Flight Agent flight physics model (once per minute). The CNS Forwarder subscribes to that message and redirects the message to the Mode S Communication model for processing. The Mode S model evaluates the circumstances for probability of message reception, considering interference factors related to air traffic congestion and other system loading configured for the simulation, LOS and proximity to Ground stations, and identifies the success or failure of that messages delivery. If the model determines circumstances are favorable for the message to be received successfully, it then applies a delay representing ADS-B ground station processing and data distribution latency as would be characteristic in ground processing of the message, and uses the destination subscription of the previously wrapped message to publish the message to the receiver Activity of the Surveillance Agent, completing delivery of the message.

ACES/CNS System Model Configuration

For configuring simulations, the user is provided access to parameters of each model and physical system elements used during the simulation. The models themselves will operate with default parameters stored and read-in from various configuration files as default operating conditions. The following is a description of the extent to which each model uses configuration information.

Communications Systems

Two different communication systems will be available in AwCNS; Analog Voice Communication that uses a VHF radio model, and CPDLC messaging using a VDL Mode 2 digital data link model.

For both systems, simulated transmission of appropriate system message types (Voice messages or CPDLC digital messages) are synchronized to the flight situation of each aircraft for gate-to-gate operations. Communication messages are provided in the form of message sequences that occur between Pilot and Air Traffic Control, initiated by either, depending on the message sequence type. Message sequences contain anywhere from two to five messages that may include instruction messages, flight information messages, instruction acknowledgements, and post boundary contact and contact acknowledgement messages. Message sequences are provided for all flight phases including departure and arrival surface communication, departure and arrival TRACON maneuver messages and frequency handoff sequences for departure/arrival TRACON fix crossings and ARTCC or sector boundary crossings. The format of the overall communication scenario was derived from a standard flight voice script that was determined to be typical of most flights.

Communication message sequences are maintained in a single Voice/CPDLC message description configuration file. From this file messages are reused as needed for each flight and for the simulated flight situation. The description file contains both Voice and CPDLC message content, but most importantly contains message parameters such as message length, message duration, message retransmission counts, and sequencing information which are used by the radio models during transmission of each message. For both of these systems, the actual content of a message is never transmitted, however the message parameters are essential to define information for each message to the appropriate communication model for the simulation. Communication messages use ACES messages or ACES reference times for events such as Pushback, Takeoff, Center crossing times etc … to initiate the start of a message sequences. This file also contains the ACES reference messages that each communication message uses for reference if needed. Also, with more recent enhancements, ACES events are used to initiate maneuver message sequences that result, after delivery of a maneuver message acknowledgement from the aircraft, in the actual aircraft maneuver.

As shown in figure 9, for the communication modeling process, other files also provide detailed information for communication, enabled simulations. These files include; an Aircraft Communication Equipment file, Ground Station Configuration file(s), a Terminal Frequency Configuration file, a file to configure Terminal areas and ARTCC's where Communications will be enabled and a VDL Mode2 Model Parameter file. All of these files are evaluated and used in either the simulation setup process or during the simulation run to provide input to the models. Input from these sources configure the modeled architecture and control the simulation.

All configuration files are available to the user for modification to allow experimentation with model parameter variations and simulation details. Also, as part of the ACES setup utility, a GUI is provided with a communication tab for simulation setup.

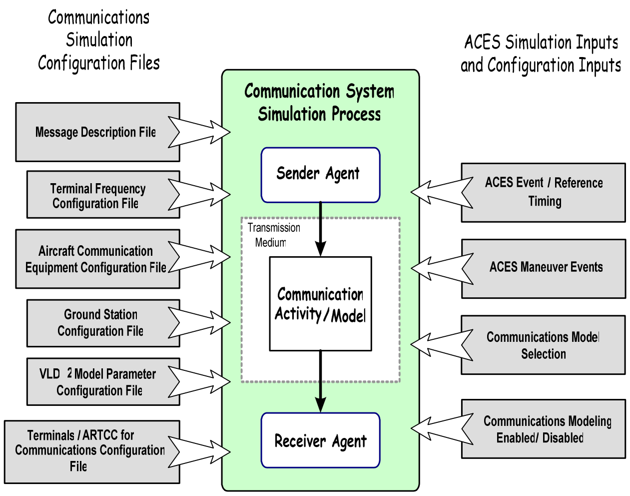

Figure 5: Communication Modeling Configuration

Navigation Systems

Navigation system models provided for ACES include a VOR/DME model as the default baseline navigation application and a GPS (Local and Wide Area Augmentation System) model from the FY06 deliverable. Both models are statistical models that randomly apply appropriate statistical variations to the aircraft true position (latitude/longitude) to derive a new reported position of the aircraft. For VOR/DME there is also a calculation of slant range, which is the distance of the aircraft on a diagonal to the nearest Navaid Ground station, which varies based on Ground Station proximity. The calculated slant range has a direct effect on reported position data.

Since GPS is primarily a standalone system, no external, configuration data or parameters are required for its use. Any statistical reference data required by the model is available as internal model parameters.

For VOR/ DME, which requires the use of Navaid Ground stations, a configuration file exists that contains a default ground station mapping derived from best available FAA data. This file can be modified to vary simulation results. Similar to GPS, statistical reference data for the internal model operation are contained in the model code.

Both the VOR/DME and GPS models have basic control parameters available through the ACES User Interface to enable their use, and for enabling their operation in specific terminal area airspace or regions. Figure 10 graphically identifies the control inputs provided through ACES and configuration files used as input to the general Navigation system modeling/simulation process.

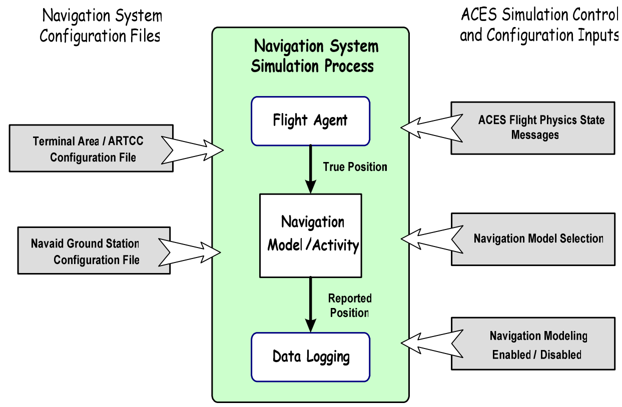

Figure 6: Navigation Modeling Configuration

Surveillance Systems

Two Surveillance system models are provided, a Secondary Surveillance Radar (SSR) statistical model as the default baseline surveillance system, and an ADS-B system model.

The SSR model implementation is similar to both statistical navigation models in that it uses the ACES Flight Physics activity state messages as input. The model processes data by randomly applying statistical variations to the true state data (Latitude/Longitude) and providing reported position data to the system. For configuration, the SSR model does not require, or have provided from the outside, any model configuration parameters but does rely on region and sector boundaries to define the location of the SSR model where applicable SSR site resides for model data processing. Reported position data and the location of the SSR site are provided as logged data.

Operation of the ADS-B system model (explained and diagramed earlier in this paper) requires either VOR/DME or GPS Navigation model output. Therefore, configuration of operating parameters of the navigation system used is available through their configuration files.
For transmitting ADS-B data, the Mode S model is responsible for analytically determining if a message generated by an aircraft at an instant of time can be received by a ground station. In order to provide the message delivery determination the model requires Ground Station locations, radio parameters, data rate information for other systems that share the Mode S radio link and location information of other aircraft in the vicinity. This data is provided as information files, and again are accessible to the user for modifications. Specific file types available for configuring the Mode S modeling capability are provided for Aircraft and Ground station radio equipment, ground station locations and Mode S communication model parameters. As output data the

logged data for the modeled ADS-B system will store modified navigation system data as affected by the end-to-end ADS-B system. Also stored as ADS-B output data will be the success rate of messages and timing information related to transmission of each message.

Both the SSR and ADS-B model have control parameters available through the ACES user interface to enable their general use, and for enabling their operation in specific terminal area airspace or regions.

Figure 11 graphically indicates control inputs provided through ACES and configuration files used as input to the general Surveillance system modeling/simulation process.

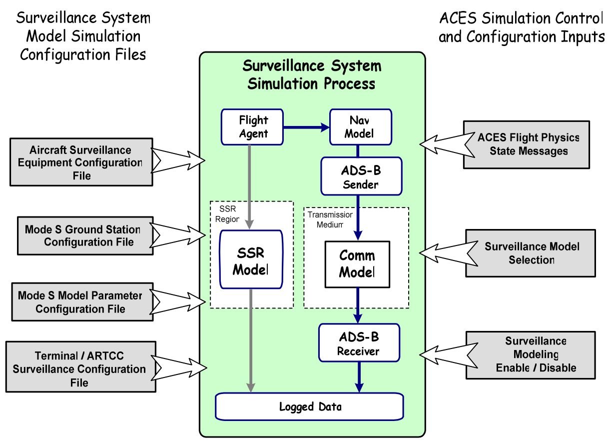

Figure 7: Surveillance Modeling Configuration

As is evident from these control and configurability options, simulations with ACES that use the CNS system models can be modified in many ways to obtain variations on ACES/CNS simulation results. The experimenter can make changes to physical system components as would be the case in modifying ground station locations, or make changes as detailed as modifying radio transmit power levels, and determine their effect on performance in a NAS-wide, multi-aircraft simulation environment. With this added level of analysis and inherent ACES, NAS agent operations, the experimenter is presented with new options to identify NAS infrastructure performance in concept studies that previously could not be addressed.

Enhanced Simulation Capabilities

After the baseline development was completed enhancements for the use of the modeled CNS systems were identified and implemented that added several dynamically functional CNS system operations. The identification of these as improvements was conveyed during the FY05 baseline review by current concept developers and from information gathered from visits to Air Traffic Control sites. Incorporation of the enhancements provides additional analysis capability to the system through more realistic CNS/NAS system interactions and provides detail to the simulations that enable a higher fidelity of CNS performance. The following are a description of these enhancements.

Voice Activated Maneuvers

In the en-route airspace, controller-pilot communications occur to initiate aircraft maneuvers. Maneuver messages that a controller issues are modeled by ACES, generated by the ARTCC ATC models (such as CDR model or re-routing model) and ACES assumes that the transmission of such messages is perfect (i.e. no delays or interference occurs). Therefore they are always delivered on time and the aircraft always responds when expected. However, in actual ATM operations, these messages are delivered via communications systems which are not ideal, messages take time to be delivered and may even be subject to delays caused by interference and subsequent retransmissions.

In adding the 'voice activated maneuver' enhancement, and with this capability enabled in a simulation, a flight will implement an ACES ATC issued maneuver only after the maneuver message sequence (i.e. A/C instruction message and A/C acknowledge message) is successfully delivered by the communication system. The process is illustrated in Figure 5 for a general rerouting maneuver. As indicated, the ACES maneuver message triggers the communication system voice or CPDLC maneuver instruction message. Assuming the aircraft receives the instruction message, the return acknowledgement message is transmitted back to the ATC after which the aircraft will perform the physical maneuver. For this operation, the maneuver is therefore delayed by (at minimum) the duration of the two message sequence, and in a more uncommon scenario where retransmissions of either message occur, could be delayed by an even more substantial time.

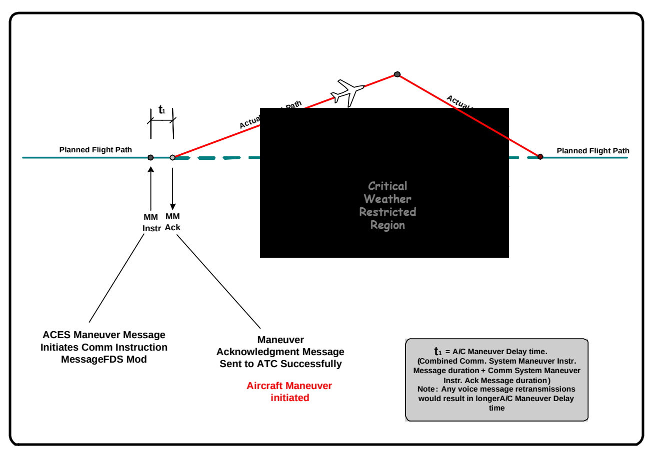

Figure 8: Voice Activated Maneuvers

En-route Short Sector Operation

An ‘En-route, Short Sector time’ operation enhancement has been included to provide more realistic representation of the number of frequency handoff message sequences that occur in a simulation. In the NAS, aircraft regularly fly for a short duration of time through sections of sectors. Based on known communication system coverage, Air Traffic Controllers make decisions as to whether new frequency assignments are required for these situations. With this enhancement enabled, and a transit time setting to reflect where these ‘no new frequency assignment decisions’ will be enforced, better realism is achieved typically lessening the number of communication messages transmitted.

Short transit time variations allow users to test the effect of different short transit times on reducing ATC workload and reduce the loading on voice channels and therefore the potential for step-on occurrences.

Chicago O’Hare (ORD)/Newark (EWR) Frequency Assignments

In the initial build of ACES with voice communication simulation capability, all airport airspace and TRACON voice communications were handled using two frequencies, one for the airport airspace and surface, and one frequency for voice communications for the TRACON. This was done because detailed terminal area definitions were not available in ACES, and therefore no means to differentiate the varied operations was available.

However, with a recent ACES upgrade of two airport terminal area definitions (i.e. ORD and EWR), an upgraded capability to provide multiple frequency assignments to accommodate traffic volume and differentiate operations in the airport/terminal area has been added. This enhancement allows for a more realistic number of communication frequencies by providing a user definable, configuration of ground station/channel assignments at airports where these distinctions can be made (i.e. ORD and EWR). This enhanced capability will more realistically simulate channel loading and thereby eliminate excessive step-on/retransmission occurrences when fewer frequencies are used.

Figure 6 illustrates a frequency configuration for these airports. In the diagram six ground stations are configured (shown in separate shaded areas) to identify their use for voice communications at this airport. With this capability, the user can define ground stations (which represent the use of individual frequencies) for pilot-controller communication for TRACON arrival and departure, airport control for take-off and landing runways in use and airport control for surface movement operations. The configuration used in a simulation will be based on the detail level of the terminal area definition or the users need to analyze various voice communication test cases.

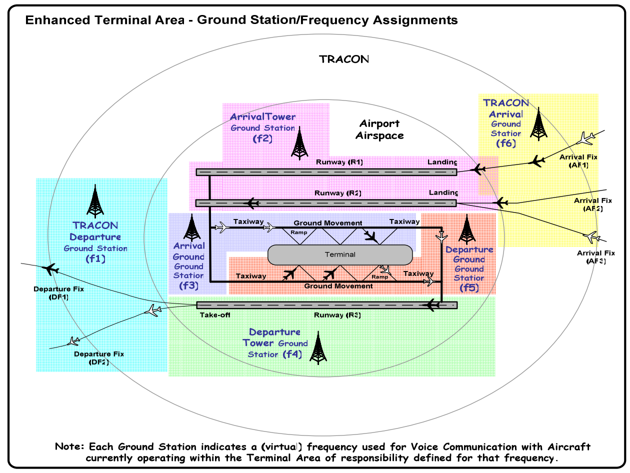

Figure 9: Enhanced Frequency Assignments

Navigation Closed loop Operation

Onboard an aircraft, Navigation systems provide position information that is used real-time for steering, either with the pilot as the controller or an auto-pilot system controlling the aircraft, which inherently creates a closed-loop system. In the initial baseline introduction of Navigation models this capability was not included, however an enhancement has been provided recently whereby user enabled, closed loop operation will allow the various simulated Navigation systems to impact flight physics, and therefore provide the capability to analyze the effect of navigational system reported positions and their associated errors. With this capability enabled the feedback of new (i.e. reported) navigational system positions will result in the change of flight track data, crossing times and arrival times compared to the results obtained from running the simulation without closed loop. For the various navigation systems provided, the accuracy of data will vary based on the system.

As shown in Figure 7, closed loop navigation is designed to operate by feeding back the Navigation model output data to the Flight Physics/Auto-Pilot/Control model.

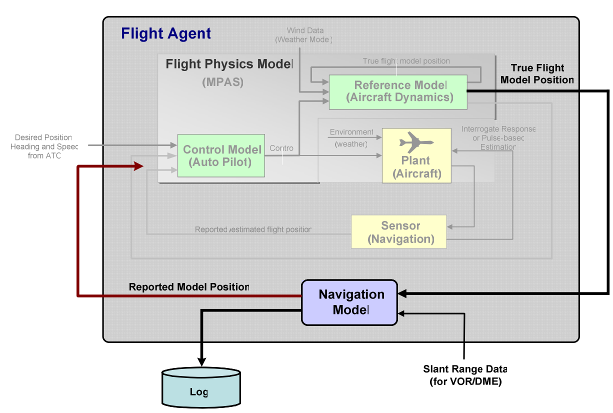

Figure 10: Navigation Closed Loop Operation

Use of this closed loop operation could be useful for evaluating simulation results for varied navigations system effects on flight time and aircraft fuel consumption.

Surveillance Closed Loop Operation

For Air Traffic Controllers, Surveillance systems provide real-time aircraft position information to monitor Air Traffic as an aid in their decision making and flight adjustments, essentially creating a closed loop (human in the loop) system. In introducing surveillance system closed loop operation, the affects of various surveillance systems accuracy will be reflected into this ATC decision making process, whereby the closed loop surveillance will provide the capability to test the effect of that accuracy on ATC models that issue maneuver messages. The surveillance error will result in changes to the content of maneuver messages compared to the maneuver messages issued in a simulation without closed loop.

Enhancements to provide this capability as a user selectable function will provide Surveillance model output (reported latitude and longitude) as a subset of the state data to the ATC Agents to provide the Surveillance model output data to the Flight Physics model.

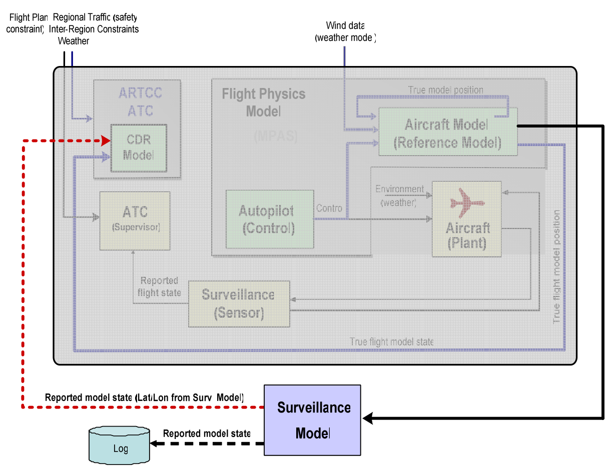

Figure 11: Surveillance Closed Loop Operation

Figure 8 provides a view of the Surveillance System model with the output of the Surveillance Activity fed back into the ATC CDR model. The ATC CDR model uses the reported flight state (reported lat/lon); instead of true flight state (Lat/Lon). Additional state parameters that are required other than latitude/longitude will remain as were provided for true state data (i.e. speed, heading, etc …).

In the next section, several ideas are identified for experimenting with the use of the CNS models as components of the NAS architecture for the study of ATM concepts.

ATM Concept Evaluation with CNS Models

In the effort to identify new NAS operations that provide more effective means to accommodate increased air traffic, NAS concept developers from academia and government are working with NASA testing new airspace concepts using ACES. As this effort is likely to continue, the following ideas are provided as new concept types or added evaluation capabilities that can be attained using CNS system modeling.

ATC Workload Assessments: With the increased workload that air traffic capacity increases will present to air traffic controllers, the added time required by ATC to manage aircraft can be determined using test cases that enable voice communications. Regardless the traffic profile established for a concept, voice communication can be enabled simultaneously, making data available that provides a reasonable approximation of the number of messages, and time consumed in delivering them, that would be typical for an operations scenario.

Since many of these type of concepts may be interested in specifically studying airspace that encounters heavy traffic congestion, such as airport and TRACON airspace, the simulation could be configured only for communications simulation in the Airport/TRACON region, which is a selectable setting provided. A simulation configured as such would provide only data that is needed, and reduce simulation run time.

Another aspect of communications systems operations that could be looked at in these concept scenarios would be to investigate the use of CPDLC for specific, non critical, communication messages. With the option to set specific message sequences to be transmitted using voice or CPDLC, a mixed mode simulation could be configured to determine what reductions in the on-air time required by traffic controllers could be realized using this new technology.

En route ATC workload assessments: Similar to using communications enabled simulations to evaluate congested airspace ATC workload, concept evaluations could provide assessments of implementing CPDLC for some of the more mundane communications that occur in the en route airspace. One example of the communications that occur is the routine delivery and exchanges for frequency assignments as aircraft transition between airspace. Information for such an assessment would be able to be collected for full day-in-the-NAS simulations, and could be specifically configured to only simulate en route airspace, or specific messages that would be relevant to the study.

Flight Track Accuracy: For studies that address aircraft movement, and evaluate aircraft trajectory accuracy or stringent spacing/positioning constraints, navigation and surveillance enabled simulations could provide data related to current or new technology systems performance to support these concepts. With the VOR/DME and GPS models providing a Pilot-view of a concept in operation, and the SSR and ADS-B models providing an ATC viewpoint, aircraft position data that is not ideal data, can give the experimenter a different perspective that could not previously been observed in testing a concept. Also, with the recent implementation of closed loop operation for navigation and surveillance, this type of concept can be tested and assessed with these systems in operation, providing direct performance feedback in each simulation.

NAS Infrastructure Architecture: To investigate new CNS systems operation and their potential to improve and help develop new NAS infrastructure architectures that best take advantage of them, simulations with this system can be configured using varied combinations of CNS systems and features simultaneously to view their net effect. With many simulation efforts for developing a technology component, tests that can be done limit simulations to analyzing one piece of information or are targeted at the device performance alone. With this system however, a simulation can added a new C, N or S model and enable the simulation to run that model with other existing NAS support models. Testing of the new component will then influence the operation of those systems also, and have a direct effect on NAS operations. The advantage in having this capability is that even in a general sense all of the NAS components involved with moving each aircraft are exercised, giving the experimenter the opportunity to tune the architecture where limitations or problems are observed.

Summary

ACES as an evaluation tool for investigating new NAS concept studies has proven itself to be valuable and effective. The results of concept developer use of ACES has provided important information that will no doubt provide new and effective operational processes that will lead to a more efficient and safer air transportation system in the future. However, in addition to the NAS ATM systems that ACES is capable of simulating, the inclusion of Communications, Navigation and Surveillance system models recently provided, and still in progress, will extend ACES capabilities. With this upgraded version of ACES, CNS system modeling can be used to investigate the impact of these equally important NAS systems to provide additional concept assessment criteria. The development of this capability has been done in a manner that provides flexibility for integration of functional system models that simplifies the development process, and provides detailed and accessible control of the models and supporting CNS architecture components required by these systems. The version of ACES with CNS models described in this paper will be completed later in FY06 as a NASA GRC deliverable to this project.

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Communications, Navigation, and Surveillance Models in ACES

Design Implementation and Capabilities

I-CNS Conference

May 1st through 3rd, 2006

Presenter – Greg Kubat (Analex Corp.)

Authors: Greg Kubat (Analex Corp.), Don Vandrei (NASA GRC), Goutam Satapathy (Intelligent Automation, Inc.), Anil Kumar (CNS, Inc.), Manu Khanna (Comptel, Inc.)

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) Integrate Enhanced CNS Simulation Capabilities in ACES
  2) Design and Integration of New Technology CNS Models
- FY07: Continue with CNS Model Integration / Possibly Address 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 Design and Integration

Configuration Capabilities available for Models and Simulations using ACES with CNS Modeling

Descriptions of recently added, Enhanced CNS Simulation Capabilities

General Concepts Ideas that Utilize CNS Modeling to Enhance Concept Evaluations

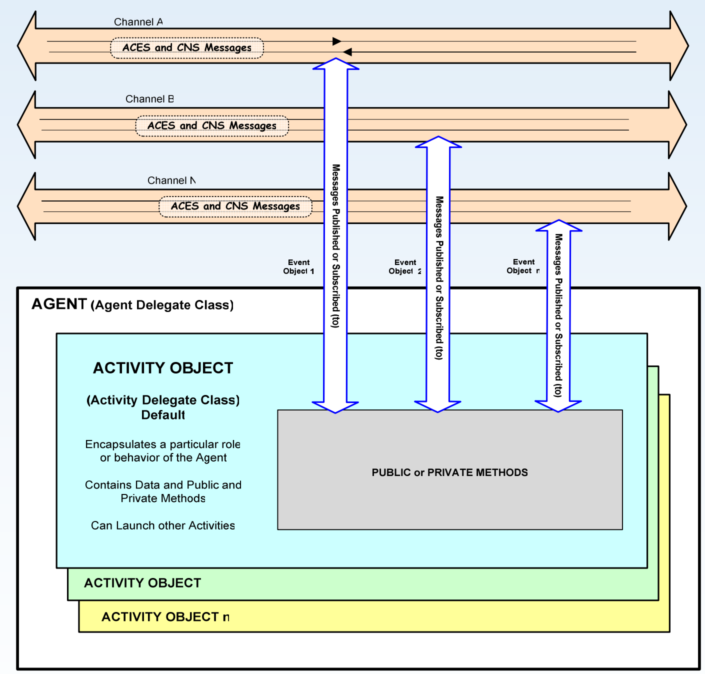
ACES – CybelePro^{tm} Agent Based Environment

CybelePro Agent Framework

- Agents – Distributed, Autonomous, Interactive Components
- Agents Communicate with other Agents to Share Information and Coordinate Activities

Agent-Activity Relationship

- Activities perform functions within the context of their associated Agent
- Activities publish and subscribe to ACES messages



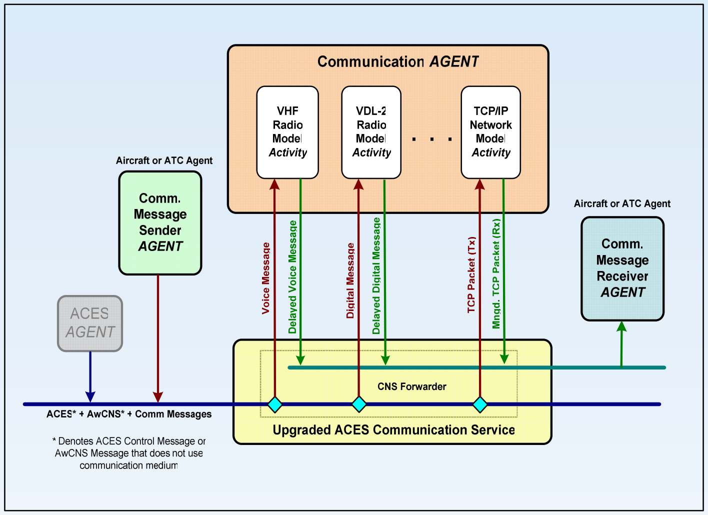
Publish-Subscribe Paradigm

- Messages are published to Tags to identify message type
- Messages are received by the Agent-activities who subscribe to those Tags

Changes to ACES Required for CNS Models

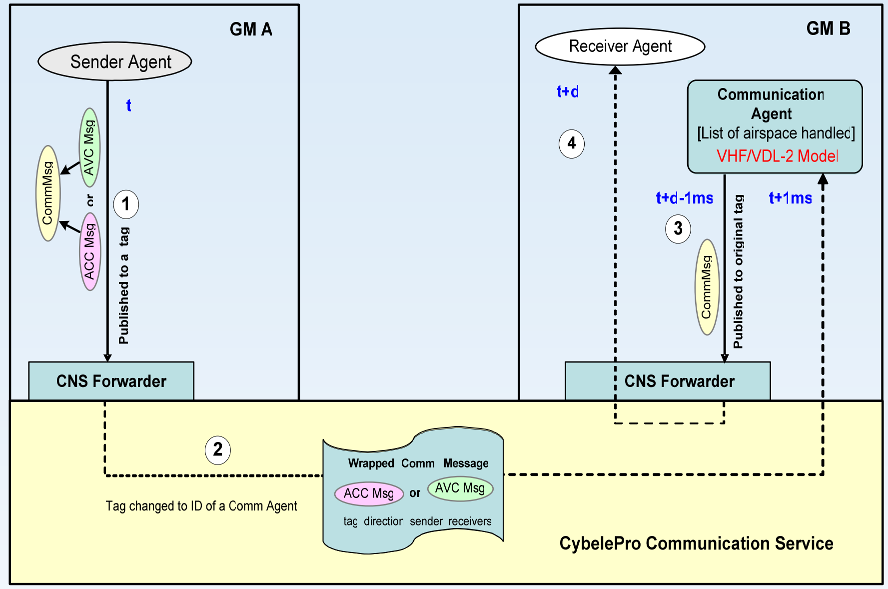
- Modified ACES 1 sec clock to 1 millisecond
- Addition of a CNS Forwarder to capture / re-tag (redirect) CNS related messages

Communication Models - Implementation



Communication Agent Design

- Contains Communication Voice and data link model activities
- Models apply radio characteristics, use model protocol, determine interference and use GS proximity for delivery of each message
- Model determines successful delivery or if retransmission is required.
- Logs message statistics (i.e. delays, duration, timestamps, other stats.)



Voice and CPDLC Message Process in ACES

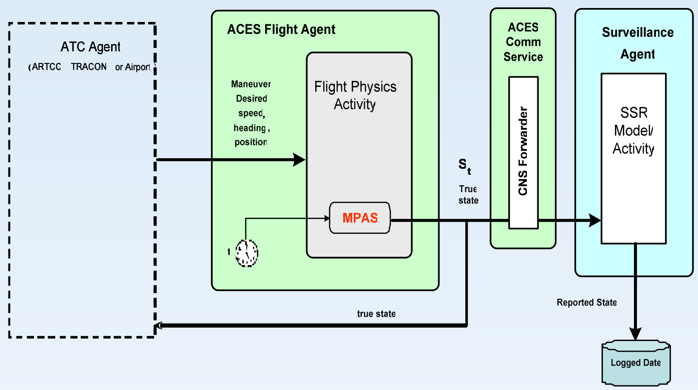
1) Voice or Data link message sent by Sender Agent

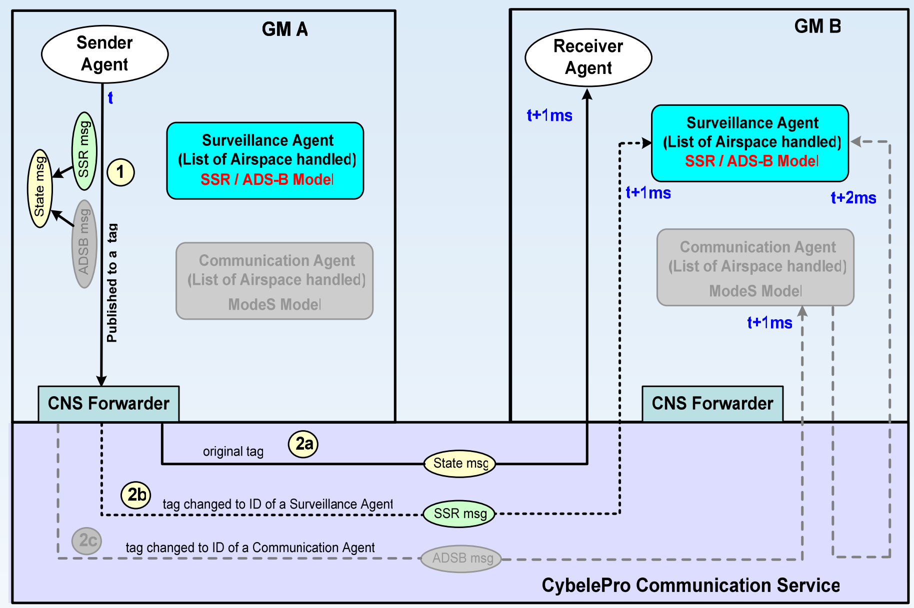
2) CNS Forwarder/Comm. Service intercept and re-Tags (wraps) each message for delivery to appropriate communication model.

3) Comm. Model publishes Messages to Receiver Agent

4) Receiver Agent Receives message

Surveillance Models - Implementation





Surveillance Agent Design

- Surveillance Agent contains Surveillance model Activities
- SSR model receives Flight Agent state messages and applies model processing.
- Logs position statistics (i.e. reported position (Lat/Long) and timestamp)

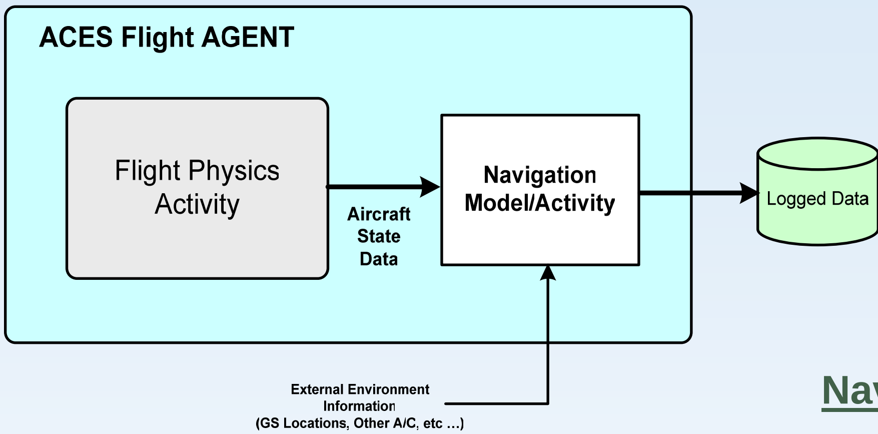
Surveillance Message Process in ACES

1) State message published by Flight Agent

2a) Message received (subscribe to) by ACES Agent

2b) State Message retagged (wrapped) for SSR activity – processed for new reported position

Navigation System Models - Implementation



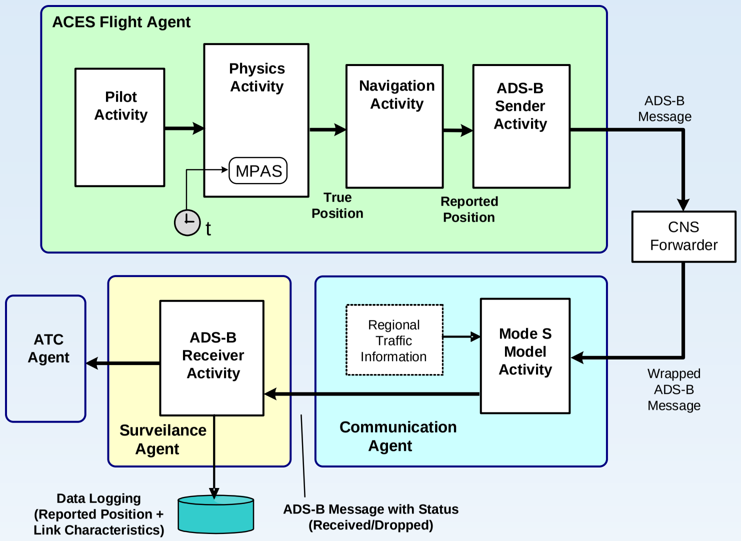
Navigation Model Design

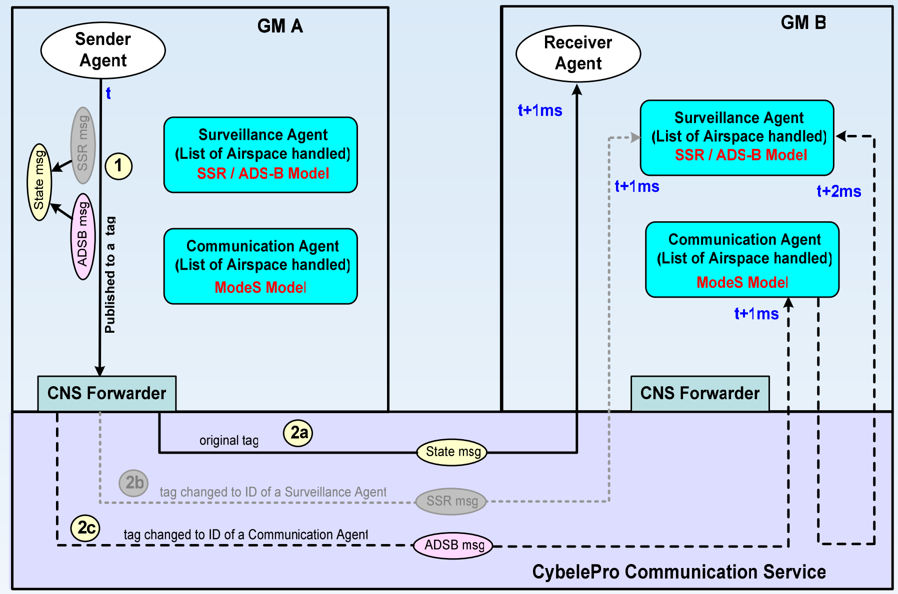
- Inherently Onboard Systems
- Navigation Models implemented as Flight Agent Activities
- Use ACES Flight Agent state message Lat/Long as Input
- Log reported position, slant range data and timestamp as output.

Navigation Message Process in ACES

- Navigation Models Receive input (Lat/Lon) by subscribing to ACES Flight Agent, State messages. (true Lat/Long)
- For VOR/DME input is provided for Ground Station locations for Slant Range determination
- New reported position statistics logged in output data files

ADS-B Surveillance Model – Implementation





ADS-B System Model Design

- System model used similar model designs from previously design models
- Delivers position, speed, heading and altitude data (1/Sec, A-G only)
- Uses Mode S Model – delivery probability
- Position data (lat/long) provided by Navigation model (ADS-B Sender Activity)
- Speed, Heading, Altitude data is from Flight Agent
- Logs output data

ADS-B Message Process in ACES

1) ADS-B Model receives data from Nav Model used for the flight.

2) CNS Forwarder publishes messages to Comm Agent / Mode S model

3) Mode S model determines probability of successful transmission

4) Successful message published to Surv Agent

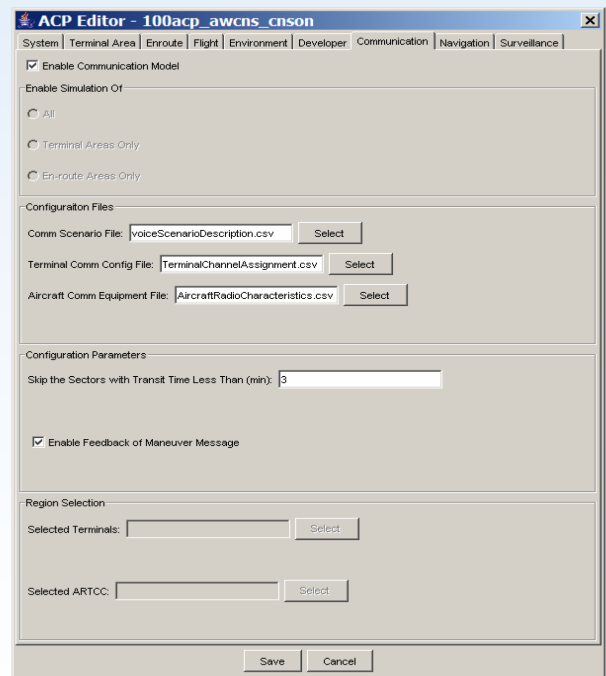
Simulation / Model Configuration

ACES Multiple Run Manager Interface provides Access to ACES Configuration GUI

ACES GUI Tabs continue to be used to Configure ACES Simulation for Flight Data Set selection and NAS Agent configuration

ACES GUI Modified with Communication, Navigation and Surveillance Tabs

- **Enable / Disable C, N or S Modeling for a simulation**
- **Set Airspace Regions where C, N or S Modeling will be active.**
- **Identify new, user-derived configuration files as options to default configuration files.**
- **Enable/Disable Enhanced C, N or S Simulation options**
- **Selection of C, N or S Model to be used in a simulation.**



Simulation / Model Configuration (cont.)

Configuration files are provided for Model Input Parameters, Model Operating Parameters and Radio Tower Locations – all User Configurable

CommunicationScenarioDescription.csv

(Message Information for Voice and CPDLC – Created from single-flight Voice Radio Script)

<u>Data Parameters</u>: Message Type, Message Set, Message Text, Datalink Command Duration, Length (Digital message), Acknowledgment Flag, Waiting Time for Retransmission, Number of Retransmission Attempts, Transmission Start-time, Reference Time, Reference Message, Reference Message Direction.

CommunicationSystemSelectionByMessageSet.csv

(Comm. Model choice for flight-segment specific, message sequence transmission.)

<u>Data Parameters</u>: Message Set (with message type description), Communication System (VDL-2 or Voice)

AircraftCommunicationEquipment.csv and ***AircraftSurveillanceEquipment.csv***

(Aircraft Radio Equipment operating parameters for Communication Models)

<u>Data Parameters</u>: Aircraft Model, Airline, VDL2 Equipment (Y/N), Mode-S Equipment (Y/N), VHF Radio/VDL-2 Radio/ModeS Radio: 1) Transmitter Power Level, 2) Receiver Sensitivity, 3) Transmit Antenna Gain, 4) Receiver Antenna Gain, 5) Loss in the transmitter, and 6) Loss in the receiver

<Sector Name>_<H-High or L-Low or S-Super>_VC_GS.csv

(VHF Radio Ground Station Configuration Files)

<u>Data Parameters</u>: NAS Facility ID, NAS Facility Type, Transmitter Power Level, Receiver Sensitivity, Location of the Tower (Note: Default mapping of VHF Radio towers locates GS at the geographical center of each sector.), Transmit Antenna Power Level, Receiver Antenna Gain, Loss in the transmitter, Loss in the receiver

Simulation / Model Configuration (cont.)

VDL2RadioGroundStationConfiguration.csv

Data Parameters: Ground Station ID, Frequencies, Location of the Tower, Transmitter Power Level, Receiver Sensitivity, Transmit Antenna Level, Receiver Antenna Gain, Loss in the transmitter, Loss in the receiver

ModeSGroundStationConfiguration.csv

Data Parameters: Ground Station ID, Location of the Tower, Transmitter Power Level, Receiver Sensitivity, Transmit Antenna Level, Receiver Antenna Gain, Loss in the transmitter, Loss in the receiver

VDLMode2ModelParameters.csv

Data Parameters: VME TG1 Timer, VME TG2 Timer, VME TG5 Timer, DLE Window Size, DLE N2 Counter, DLE N1 Parameter, DLE T4 Timer, DLE T2 Timer, MAC T1 Timer, and MAC T2 Timer

ModeSModelParameters.csv

Data Parameters: Broadcast Rate of ADS-B messages, Broadcast Rate of TCAS messages, Broadcast Rate of SSR Messages

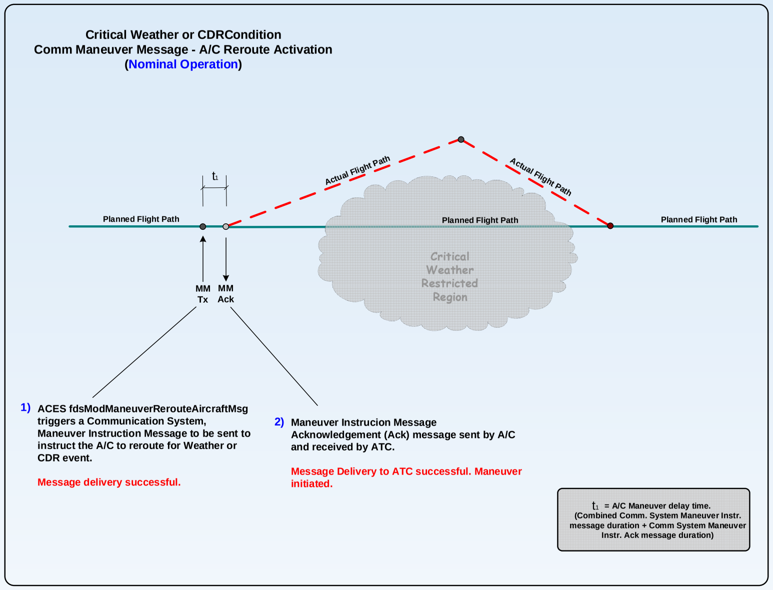
TerminalsForCommunications. ARTCCForCommunications, TerminalsForSurveillance ARTCCForSurveillance, TerminalsForNavigation, ARTCCForNavigation

Data Parameters: TRACON ID's or ARTCC's that will be in operation for a simulation for Communication, Surveillance or Navigation (respectively).

NavigationTopology.csv *(Used for VOR/DME)*

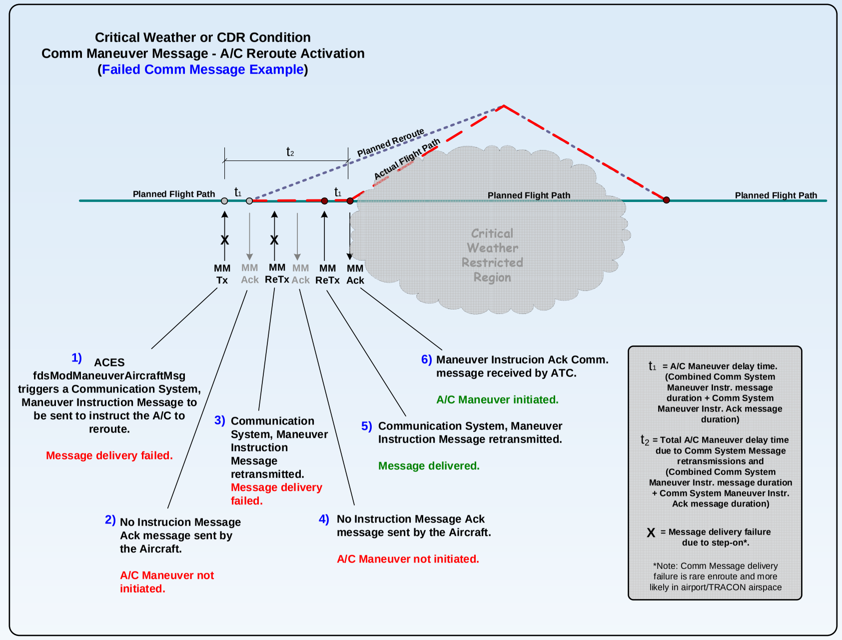
Data Parameters: Navaid Facility ID, Navaid Location, Navaid Altitude

Enhanced Capabilities - Voice Communication Activated Maneuvers



Communication Message Activated Maneuver (Default Operation)

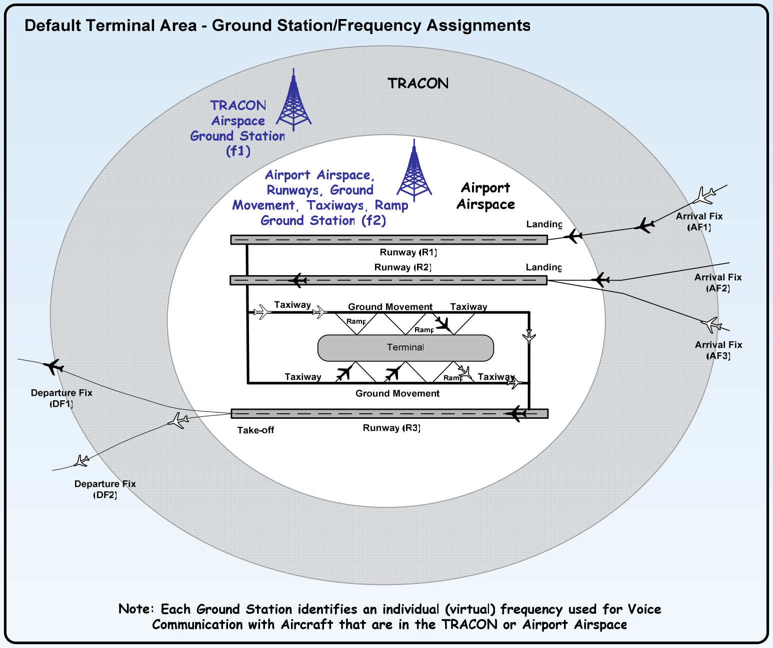
- ACES Maneuver Message are directed to a flight to perform a maneuver
- ACES Message Intercepted & Voice Msg is sent to instruct the aircraft maneuver
- Aircraft acknowledges maneuver instruction w/acknowledgement Msg
- Aircraft maneuver initiated

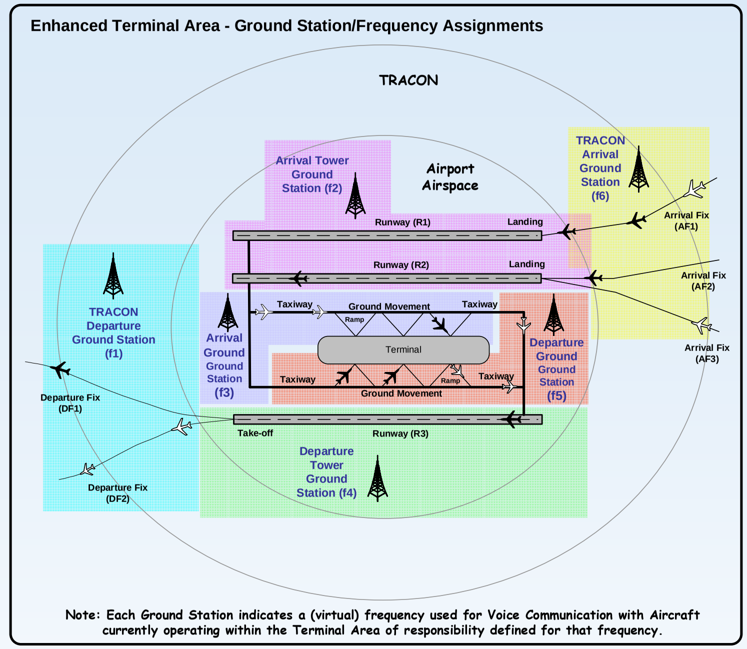


Communication Message Activated Maneuver (Msg Retransmissions Required)

- Voice instruction or acknowledgement for maneuver requires retransmission due to step-on or interference
- Delays the aircraft from receiving the instruction for the maneuver

Enhanced Capabilities – Extended Frequency Assignments





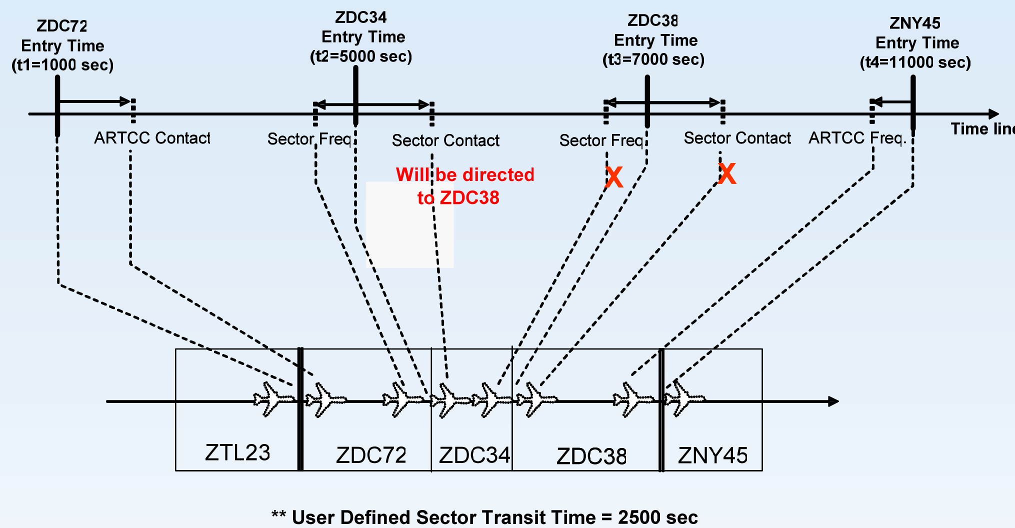
Default Airport Airspace Frequency Assignments

- Two Radio Towers used as VHF radio frequencies/channels at each airport
  (1 Airport, 1 TRACON)
- Baseline approach - sufficient for simulation purposes

Upgraded Airport Airspace Frequency Assignments

- ACES provided enhanced Airport terminal definition for Chicago (ORD) and Newark (EWR) airports (Late FY05)
- Provides the opportunity to distinguish various airport operations
- Default for ORD & EWR includes Gate/Ground, Taxiway/Landing/Takeoff and TRACON for Arrival & Departure

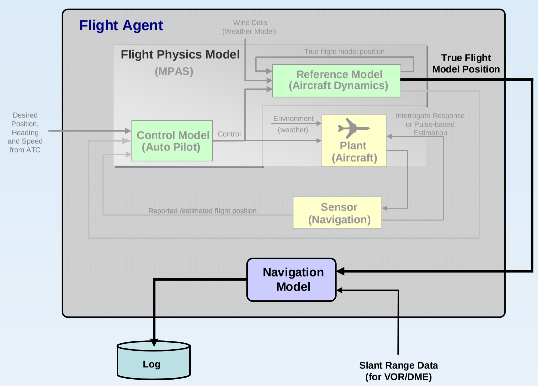
Enhanced Capabilities – Short Sector Transition Frequency Handoff



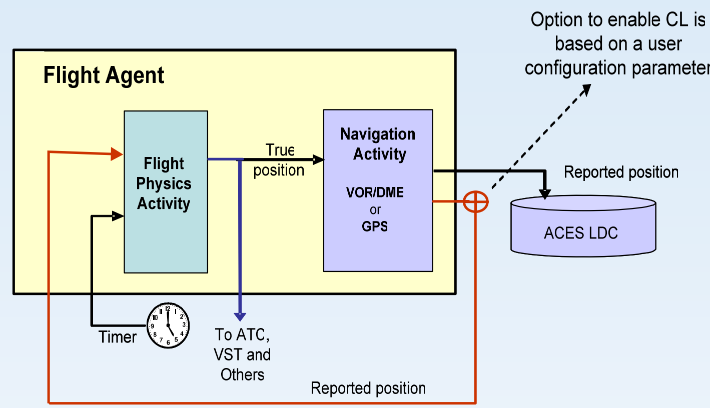
Eliminates unnecessary ATC Freq. Handoff message sequences for en-route Sector Transitions

- **Default Communications will simulate a frequency handoff message sequence for all Centers/Sector transitions**
- **Short Sector transition enhancement enacted based on ARTCC visit to ZOB (May 05)**
- **Controllers do not provide new frequencies for short sectors operations. Take responsibility for known short sector on current frequency.**
- **Enhancement improves reality of ATC/Pilot Communications**
- **User selectable – Transition Time Setting determines skipped segment Decisions**

Enhanced Capabilities – Navigation Closed Loop

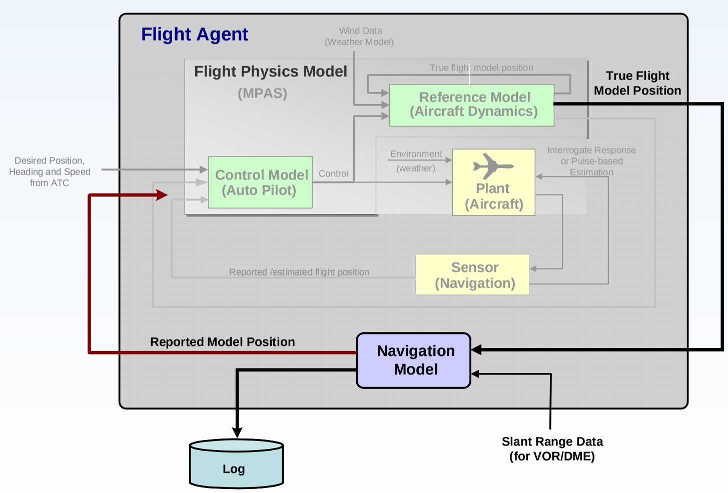


Open Loop



Closed Loop - Agent/Activity Operation

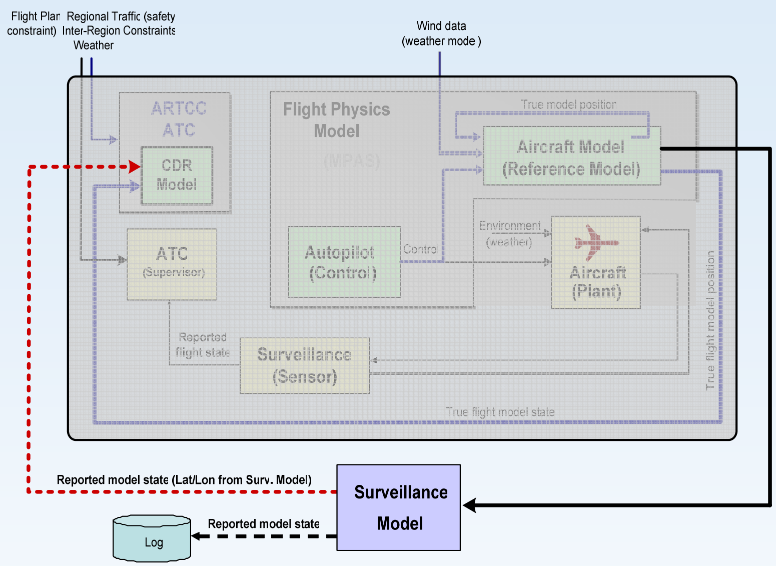
Closed Loop

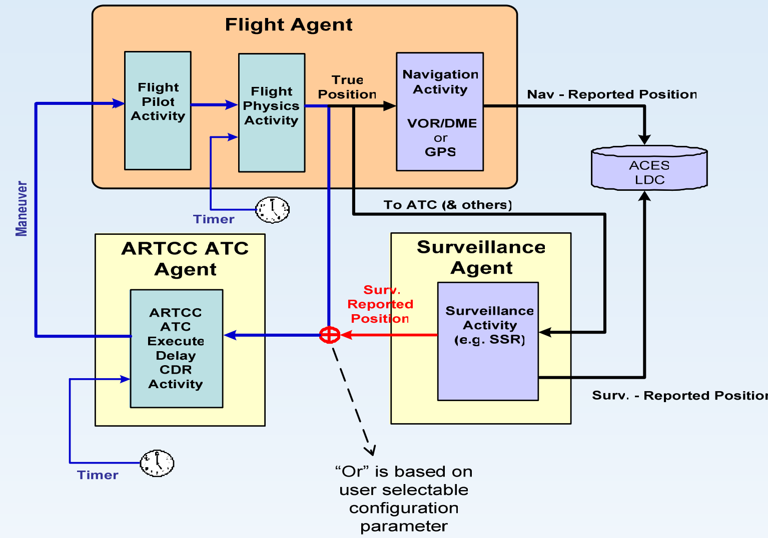


Upgraded for Navigation Model Position Feedback

- Provides non-ideal position to Flight Agent from Navigation model.
- Provides the effect of a non-ideal flight path on flight times for fuel consumption evaluations or spacing for separation studies. (Pilot/autopilot – view).
- Could be most useful in congested airspace

Enhanced Capabilities – Surveillance Closed Loop





Upgraded for Surveillance Model Position Feedback

- **Provides non-ideal position to ATC Agents from Surveillance System model.**
- **Provides the effect of a non-ideal (ATC-view) for ATC Agent decisions for directed maneuvers.**

New Concept Types or added Evaluation Capability

Air Traffic Controller Workload Assessments

- **Evaluate Critical Airspace (Airport Airspace) or Gate-to-Gate (including en-route airspace) operations for ATC voice communication workload**
- **Evaluate use of CPDLC with Voice communication (Mixed Mode)**

Flight Track Accuracy / Aircraft Spacing Concepts

- **Use Navigation System Models to perform more informative assessments of concepts designed to provide more efficient aircraft spacing.**
- **Use Closed Loop Navigation to determine how varied Navigation systems could affect aircraft fuel consumption.**

Architecture Performance Concepts

- **Combine Several CNS system models to evaluate general NAS infrastructure performance.**
- **Enable Navigation and Surveillance system closed loop and vary the N & S systems to assess the effect varied system accuracies have on reported CDR events.**
- **Enable Closed Loop Navigation with Communication Activated Maneuvers to assess the impact of delayed maneuver initiation and non-ideal maneuverability for increasingly congested airspace.**

CNS Modeling can be run to enhance any Concept Simulation