

ACES Surveillance Modeling

Design Implementation and Capabilities

I-CNS Conference

May 5th, 2008

Presenter – Rafael Apaza/Steve Bretmersky

Greg Kubat (Analex Corp.), Steve Bretmersky (CSU), Rafael Apaza (FAA),
Thanh Nguyen (Analex Corp.)



ACES Simulation Tool - Description/Overview

Airspace Concept Evaluation System

What is ACES?

ACES is an event-based, gate-to-gate software simulation of the NAS with Interacting autonomous agents. Agents represent NAS ATM and ATC entities

- Simulates the propagation of information (and disturbances) via event and communications between agents
- Simulates how the rules and procedures of independent agents may interact.

Why ACES?

- Future demands with 2-3 times current traffic are envisioned for 2025
- New operational concepts with greater use of automation and information distribution will be required

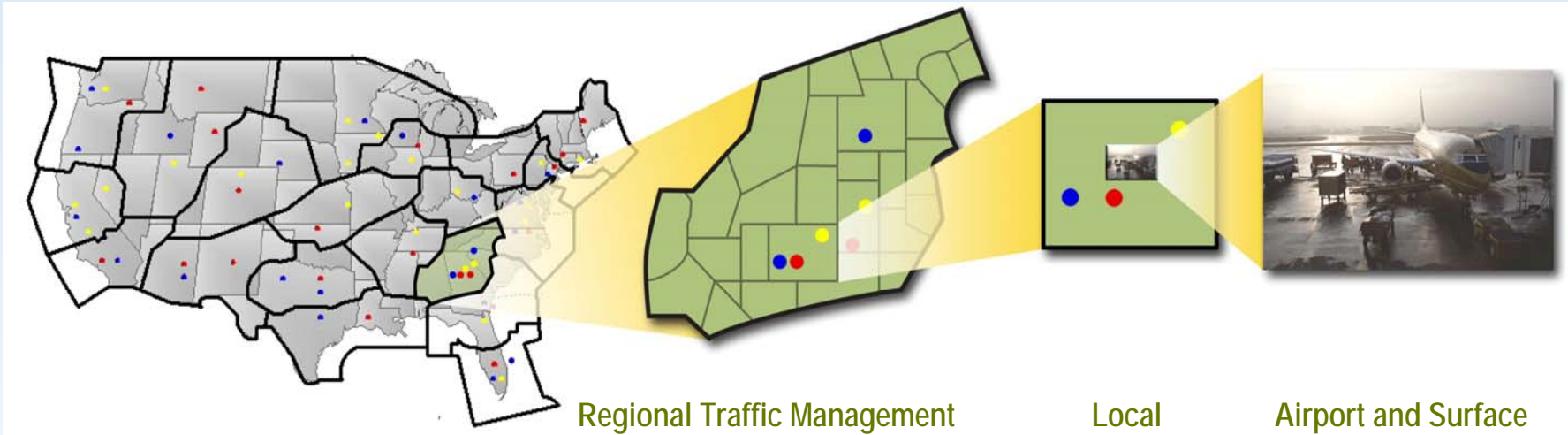
ACES was developed to model new operational concepts that rely on greater information transfer and increased coordination among NAS participants

Courtesy NASA ARC



ACES Simulation Tool - Description/Overview

ACES Core Physical Models



National Traffic Management

Fast-time, nationwide gate-to-gate simulation of ATM-FD-AOC operations

- Full flight schedule with flight plans, 4-D gridded winds, gate-to-gate operations

Regional Traffic Management

Thousands of participating agents:

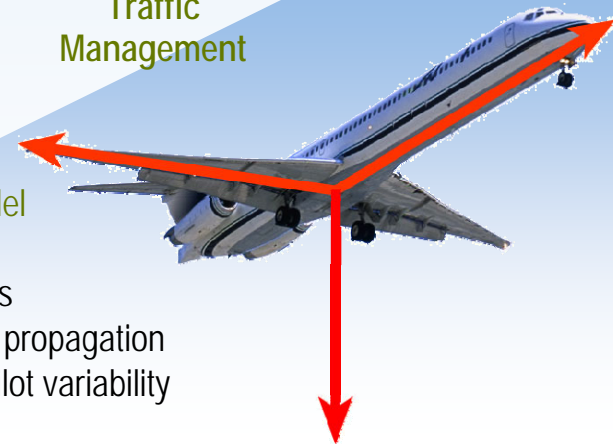
- National 1
- Regional 20
- Local 100s
- Airports 100s
- Aircraft 10,000s
- Airlines 10s

Local Approach and Departure Traffic Management

Airport and Surface Traffic Management

High Fidelity 4-DOF Trajectory Model

- Based on laws of physics
- Realistic pilot-based control laws
- Includes elliptic-Earth trajectory propagation
- Contains modeling for aircraft/pilot variability



Courtesy NASA ARC

ACES NAS Simulation with CNS Models - Overview

ACES with CNS Models is an Upgrade to ACES - Developed at GRC during FY05/06

Integrates CNS Infrastructure Models into the ACES Simulation Environment

- Augments ACES with functional, integrated CNS system models.
- Takes full advantage of ACES functionality including NAS ATC and ATM Agent/Models and Flight Operations
- Models Introduced: VHF/Voice, CPDLC over VDL2, GPS and VOR/DME Nav, SSR and ADS-B Surv
- CNS Enhancements added to provide integrated ATM/CNS operations. Enhancements allow interaction between CNS Systems and flight, ATC and ATM operations.
- AwCNS generates detailed CNS system performance data in NAS-wide, air traffic environment.
- System design is flexible for integration, operation and improvement to CNS models.
- Fully configurable for Aircraft/CNS equipage and for varying CNS system operating parameters.

Upgrades/improvements continue today through NASA Research Announcement



ACES Surveillance Models - Overview

An SSR and ADS-B Model have been implemented in ACES to provide simulated, reported position of aircraft, as seen by ground ATC.

Secondary Surveillance Radar – Statistically models the following SSR attributes

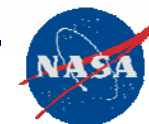
- **Radar Precision:** Inherent Accuracy of the Radar
- **Message Resolution:** Resolution of the field in a message that provides the A/C location from the Radar to the Tracking System. Model assumes Common Digitizer – 2 format.
- **Display Delay :** Time between the surveillance message being transmitted from the track processor site and the location of the aircraft being displayed on the controllers console.
- **Smoothing Function:** Keeps target reports from “jumping” on the controller’s console as each report is received. Accommodated in A/C turning. Modeled for Enroute site and Airport Site by rotation rate.

Automatic Dependent Surveillance Broadcast - Model Attributes

- **Derives ADS-B Message data** from configured onboard Navigation Model (VOR/DME or GPS)
- **Simulates once-per-second (default) Transmission of ADS-B Messages** via ModeS Model
- **Provides ADS-B Message Delivery Probability:** The ModeS model considers Broadcast Range, Received Power, and Interference due to number of ATCRBS, TCAS and other ADS-B messages.
- **Message Delivery Success Status** is determined on a per message basis. Output provides statistical data for message delivery success rates.

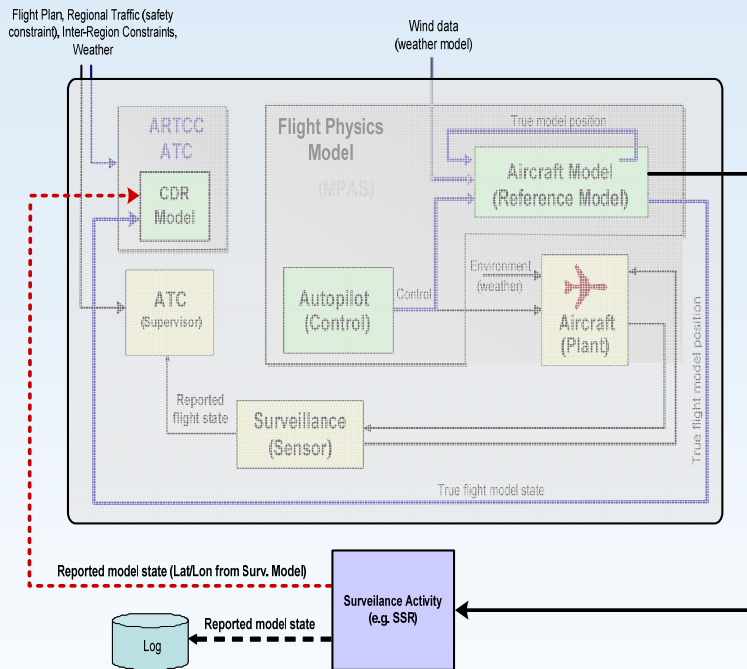
Surveillance Simulation Features

- Surveillance System modeling can be enabled/disabled in a simulation
- Aircraft Surveillance system equipage can be varied by Aircraft-type/Airline in a simulation
- Can operate Closed Loop for ATC/CDR decision-making response to reported position



SSR Model Implementation

Description



Receives ACES Aircraft model True (ideal) Position - generates new Reported Position

Statistical model – Provides A/C position deviations based on errors due to Radar Precision (CD-2), Track Smoothing and Display Delay

Smoothing Error accuracy applied based on Airport SSR site operation (at 15 rev/min) and Enroute SSR sites (at 5 rev/min)

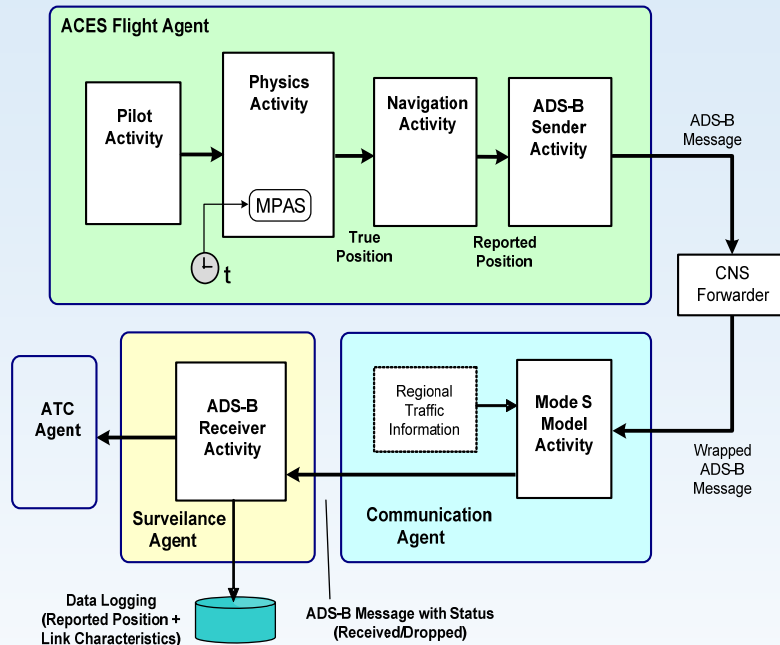
Logs reported position data on a per flight basis.

Recent Upgrades

- **Addition of higher fidelity Airport Airspace SSR Site model with 15 rev/min accuracy.**
- **Improvement to apply smoothing during Aircraft turns based on detected A/C bank angle**

ADS-B Model Implementation

Description

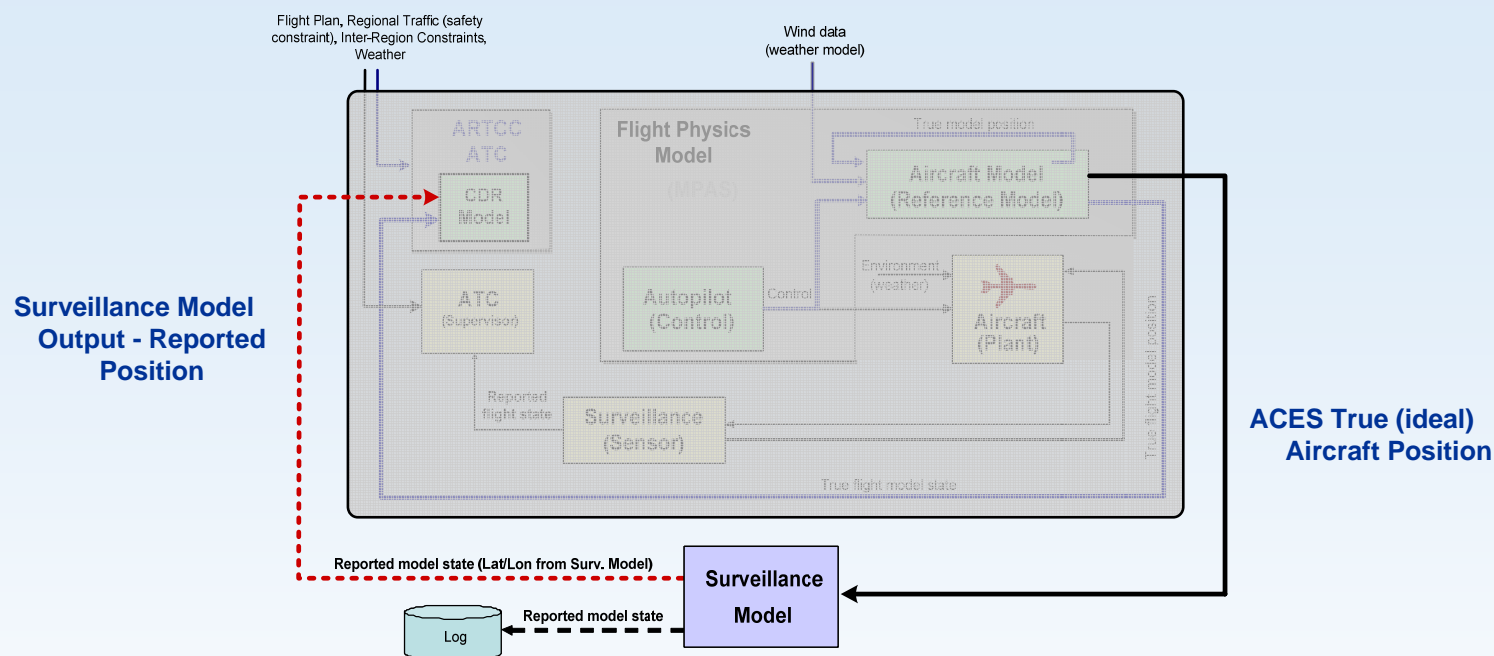


- Simulates A-G transmission of ADS-B messages that deliver Position, Speed, Heading and Altitude data.
- Uses Mode S radio model to determine per message received/dropped status and to provide message delivery probability statistics.
- ModeS Probability of Delivery takes into account Airspace traffic loading for interference potential from A/C equipped with SSR, ADS-B and TCAS.
- Position data (lat/long) provided by Navigation System model. Navigation System Model is user selectable in a simulation.
- Logs ADS-B messages and ground system delay statistics.

Recent Upgrades

- Improved ModeS interference modeling from TCAS, ADS-B, ATCRBS equipped A/C
- Improved count of A/C with specific equipage in specific airspace.
- Upgraded to provide message frequency variations for TCAS, ADS-B, ATCRBS
- Upgrade to enable/disable SSR equipage onboard ADS-B equipped Aircraft.

ACES Surveillance Models - Closed Loop



Surveillance Model Position Feedback

- Provides non-ideal position to ARTCC ATC CDR Model from Surveillance System model.
- Provides the effect of a non-ideal (ATC-view) for ATC CDR decisions for detected conflict maneuvers and rerouting maneuvers.

Surveillance Modeling Configurations

Aircraft can be equipped with different Surveillance System models to provide the experimenter with varied Surveillance system data for Evaluation and Analysis.

Top Level Configuration – established using *ACES CNS Equipment File*
(Equipment File sets Aircraft equipage on a per Aircraft Type/per (Airline) AOC basis)

Surveillance System Configuration Options:

- **SSR only** – Output data provided from the Statistical SSR Model only.
- **ADS-B with GPS as Navigation Model** – Output data reflects ADS-B transmitted messages that carry GPS Navigation model Lat/Long data generated by the GPS system onboard the A/C
 - GPS Navigation Model is configurable for LAAS in Airport Airspace / WAAS in Enroute Airspace
- **ADS-B with VOR/DME as Navigation Model** - Output data reflects ADS-B transmitted messages that carry VOR/DME Navigation model Lat/Long generated by the VOR/DME system onboard the A/C
- **For ADS-B message interference Analysis**
 - Settings are available for operation with and without SSR equipage to allow evaluations as NAS transitions to all ADS-B airspace.
 - ADS-B, TCAS, SSR message frequency parameters are user configurable.

Surveillance Models – Standard Deviations/Calculations

SSR Model

σ_1 = Smoothing Standard Deviation* (2750 feet for En-route SSR Site, 918 feet for Airport SSR Site)

σ_2 = Radar Precision Standard Deviation (Common Digitizer-2 applied for enroute - limitation 439 feet)

σ_3 = Display Delay Standard Deviation (1.7 seconds times the A/C speed)

Components are combined using Root-Mean-Square to determine position error

$$\sigma_{\bar{x}_w} = \sqrt{(\sigma_1^2 + \sigma_2^2 + \sigma_3^2) / 3}$$

Note: Smoothing error is only applied when A/C is determined to be in a turn where the A/C bank angle is greater than x degrees. (currently set to 1deg.)

ADS-B using GPS (as onboard Navigation*)

For Standard GPS: Standard Deviations = 3.15 meters for Latitude/Longitude, 4.75 meters for Altitude

For GPS (WAAS): Standard Deviations = 0.91 meters for Latitude/Longitude, 1.07 meters for Altitude

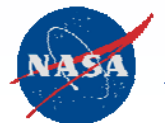
For GPS (LAAS): Standard Deviations = 3.10 meters Latitude/Longitude, 1.0 meters for Altitude)

ADS-B using VOR/DME (as onboard Navigation*)

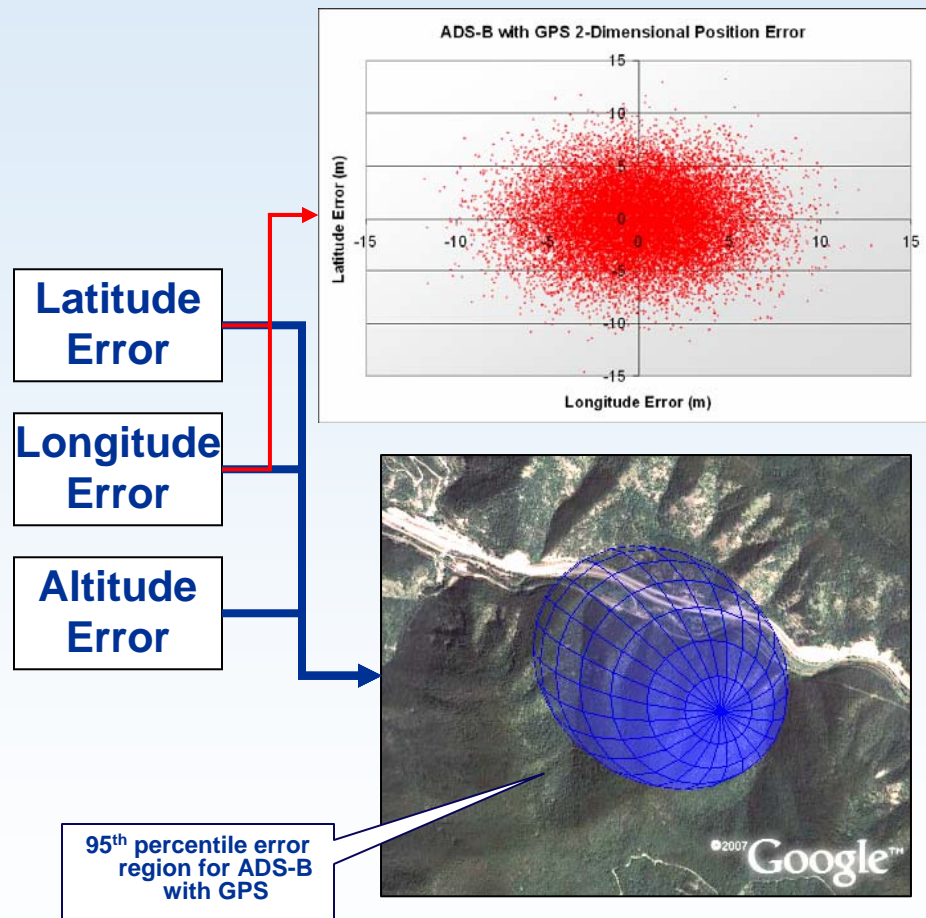
VOR Heading Standard Deviation = 0.5 degrees

DME Standard Deviation = 1 nm (with influence from individual aircraft 'slant range' determination)

* Standard deviations are applied in the Navigation model configured for the simulation.



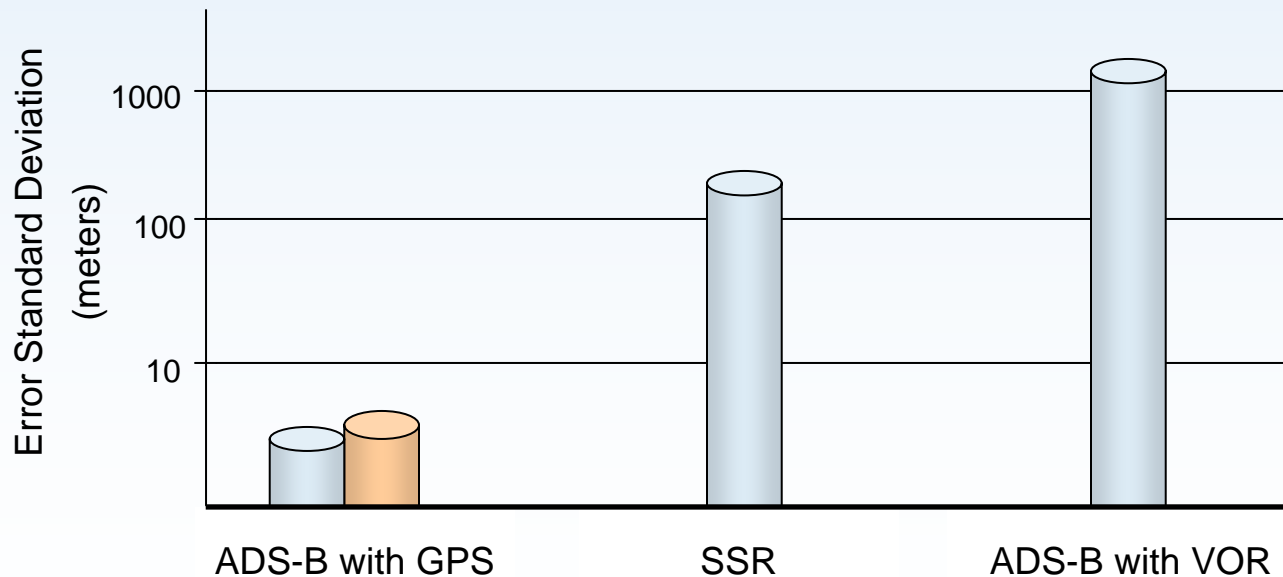
ACES Surveillance Models – Reported Position Characterization



- Analyzed true and reported position data from ACES with CNS simulations:
 - SSR only
 - ADS-B with VOR
 - ADS-B with GPS
- Compared the 1-dimensional error components for latitude, longitude, and altitude to the expected standard deviations
- Calculated the three-dimensional 95th percentile error regions for each model
- This work confirms the models behave as expected in the ACES implementation

Reported Position Characterization Results

- Standard deviations calculated for the latitude, longitude, and altitude error components for each model
- The SSR and ADS-B with VOR/DME models do not contain altitude error components yet
- ADS-B with GPS provides far better precision than SSR or ADS-B with VOR/DME



ADS-B Model – ModeS Radio - Delivery Probability Calculation

Probability of Long Message Reception $P_{t,A_nGS_m} = P_{A_nGS_m} \times P_a \times P_s \times P_l$

$P_{A_nGS_m}$ = Probability of correct long message reception at the nth Ground station Transponder (GS) sent from nth Aircraft Transponder in a no-interference case, based on broadcast range

P_a = Probability of long message reception at the nth Ground Station in the presence of Mode A/C messages (SSR)

P_s = Probability of long message reception at the nth Ground Station in the presence of short messages from TCAS

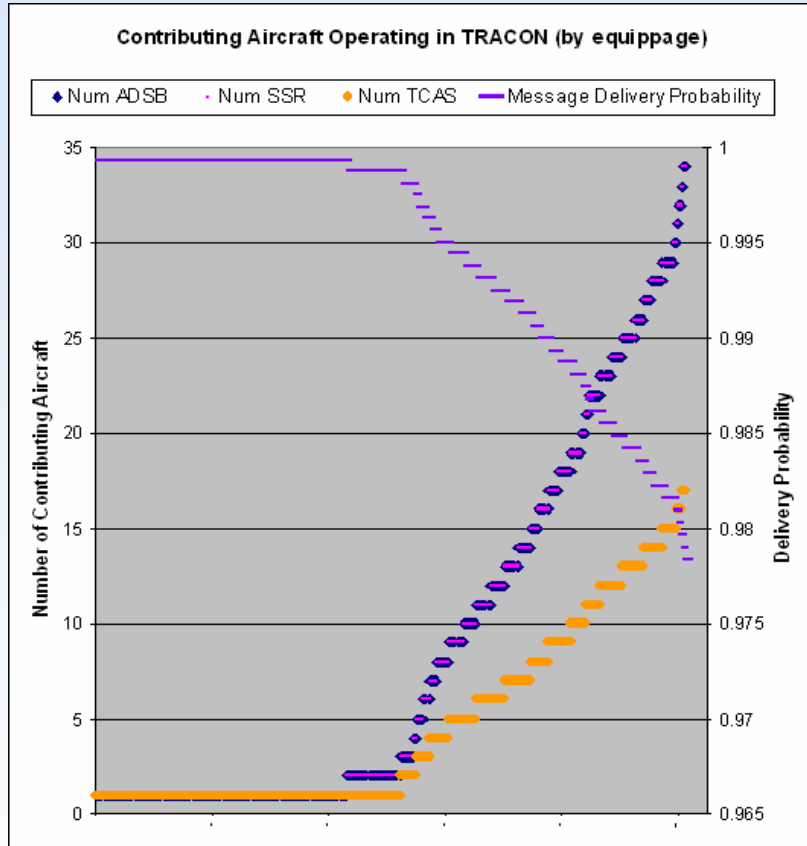
P_l = Probability of long message reception at the nth Ground Station in the presence of other long (ADS-B) messages

Calculation takes into account:

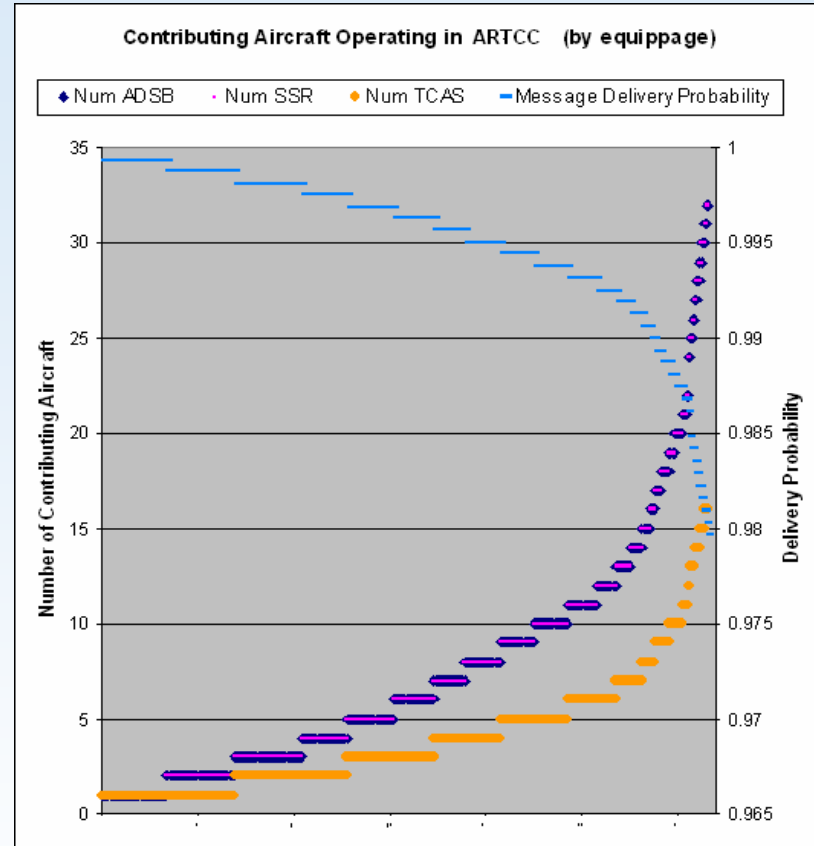
- The number of aircraft that are equipped with TCAS, ADSB or ATCRBS (Mode 3A/C) operating within range of the aircraft that is being evaluated for probability of an ADSB message transmission.
- The message frequency (messages/sec) values provided for TCAS, ATCRBS and ADSB
- The length of time Mode S squitter is vulnerable to short ModeS (TCAS), long ModeS (ASD-B) and ATCRBS messages.

ADS-B Sample Data - Message Delivery Probability Statistics

TRACON Airspace



ARTCC Airspace



Data for ADSB message delivery probability collected from a 639 Flight simulation.

Each data point represents an instance of a probability of delivery calculation at the time of an ADS-B message transmission in ARTCC or TRACON airspace vs. the number of ADS-B/SSR/TCAS equipped aircraft in that airspace that contributed to the probability value.

Trend shows that Probability of Message Delivery decreases as number of Aircraft/Interferers increases.

ACES Surveillance Model – Recommended Improvements

- **A/C Track Processing Model** - Model that would provide output data for ADS-B and SSR that reflects improved ATC Display processing
 - Perform more detailed sorting/evaluation (data fusion) of Surveillance messages by data quality criteria
 - Utilization of available message latency information to evaluate quality of surveillance data (SSR and ADS-B) provided as ATC, displayed Output data
- **Barometric Altitude Sensor Model in SSR model (In-work)**
 - Currently no reported Altitude Data is provided in SSR model
- **Post Processing tools for Surveillance model performance analysis**
- **Configuration options for Dynamic GPS to VOR/DME Navigation system transitions or ADS-B to SSR system transitions between Airspace regions.**
 - Would allow for evaluations of GPS failure modes and the potential fallback to VOR/DME system accuracy as ADS-B system navigation data (if this is being considered)
 - Would allow for evaluations of **fallback transition** to SSR operations in ADS-B failure scenarios.
- **Configuration options that allow for closer integration of ACES operations with CNS models operations.**
- **Complete/formal verification of ACES, CNS models performance.**

Potential Surveillance Modeling Analysis Capability with ACES

Perform Separation Standards Analysis to Investigate ATC Operational Guidelines and Standards for ADS-B Equipped NAS

- Simulate/evaluate NAS separation data for current NAS Operations and Surveillance systems.
- Implement detailed and NAS-wide simulations using ADS-B w/GPS.
- Evaluate ADS-B simulation results to assist with developing safe separation criteria.
- Investigate for current Operations and new Concept of Operation scenarios.
- Evaluate for en-route and terminal domains.

Surveillance System Failure Modes Analysis

- Simulate ADS-B Radio anomalies in large scale simulations
- Simulate GPS Outages and/or GS Operations failures
- Analyze results for failure/fallback operating scenarios and workarounds

Summary

ACES is a powerful, high quality application for large scale, NAS-wide Airspace Concept evaluations

Integration of new technology Surveillance Models (as well as Communication and Navigation models) enhances ACES capabilities to study new concepts with integrated CNS infrastructure models

Closely coupled CNS modeling in ACES is essential to new Airspace Concept, Proof of Concept and eventual implementation in the US NAS

Additional work needs to be done to improve current ACES / CNS models capabilities and quality. Existing model integration was done at minimal level of effort. NRA – in work to provide improvements

Proof of the capabilities of this application as a research tool need to be pursued through additional research efforts using the application.

Current/ongoing NAS upgrades and interest in Surveillance system operational improvements would be an ideal forum for the use of ACES as a research tool to assist in this large scale effort