- Overview of NASA GRC Modeling, Simulation and Analysis Capabilities
  - ACES with CNS
  - OPNET
  - Other
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- Some Simulation Examples
- Summary of Simulation Tools and CNS Models

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AwCNS Presentation Outline

- **ACES Description/Overview**
- **AwCNS Models Description**

  VHF Voice, CPDLC VDL-2, VOR/DME, GPS w/LAAS-WAAS, SSR and ADS-B
- **AwCNS Enhanced Capabilities Description**

  ORD/EWR Enhanced Frequency Assignments, Comm Activated Maneuvers
  Nav. and Surv. – Closed Loop Operation
- **AwCNS Models and Simulation Configuration Capabilities**
- **Simulation Examples and Requirements Test Results**
- **AwCNS Models Applicability to NAS Analysis**

AwCNS

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ACES Simulation Tool - Description/Overview

Airspace Concept Evaluation System

What is ACES?

An event-based, gate-to-gate simulation of the NAS with interacting autonomous agents.

- 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?

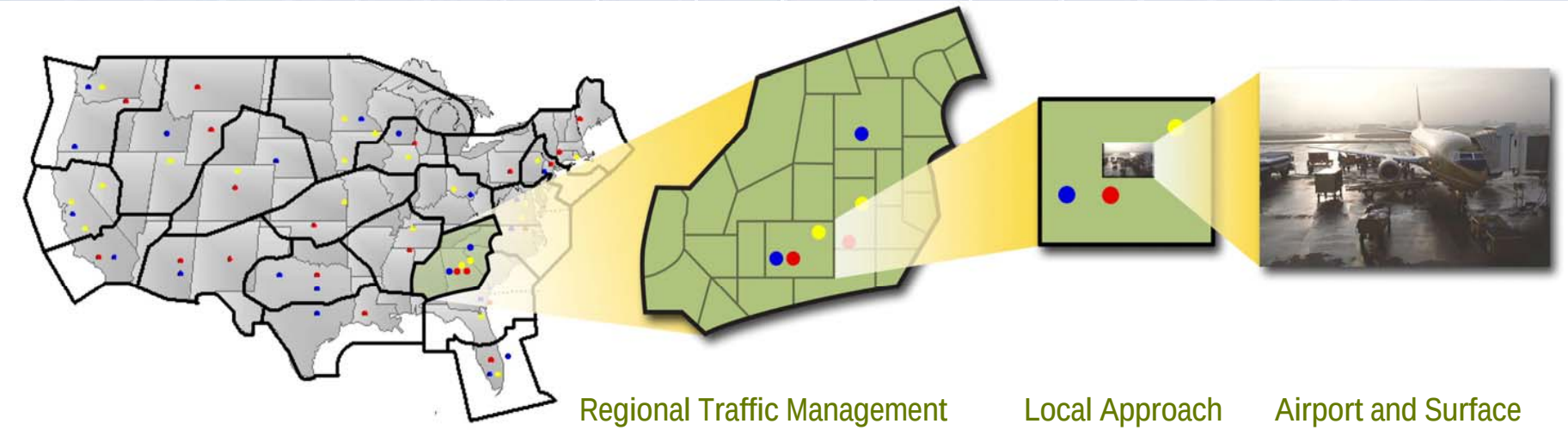
- Future demands with 2-3 times current traffic are envisioned for 2025
- Planned improvements to existing operations can not meet this demand
- New operational concepts with greater use of automation and information distribution will be required

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

AwCNS

ACES Simulation Tool - Description/Overview

Airspace Concept Evaluation System



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

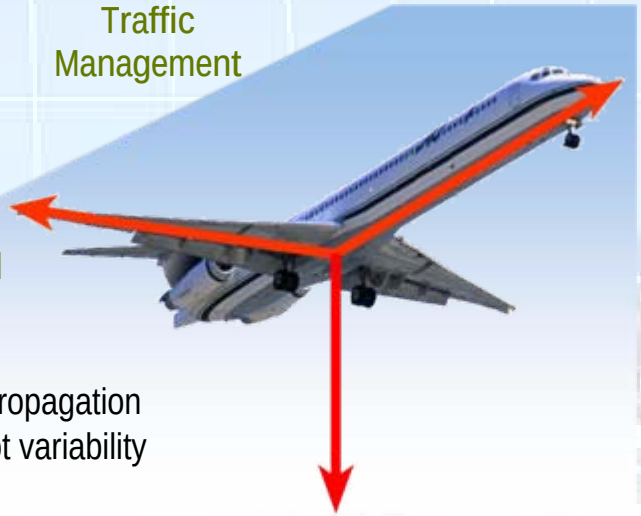
Regional Traffic Management

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



Courtesy NASA ARC

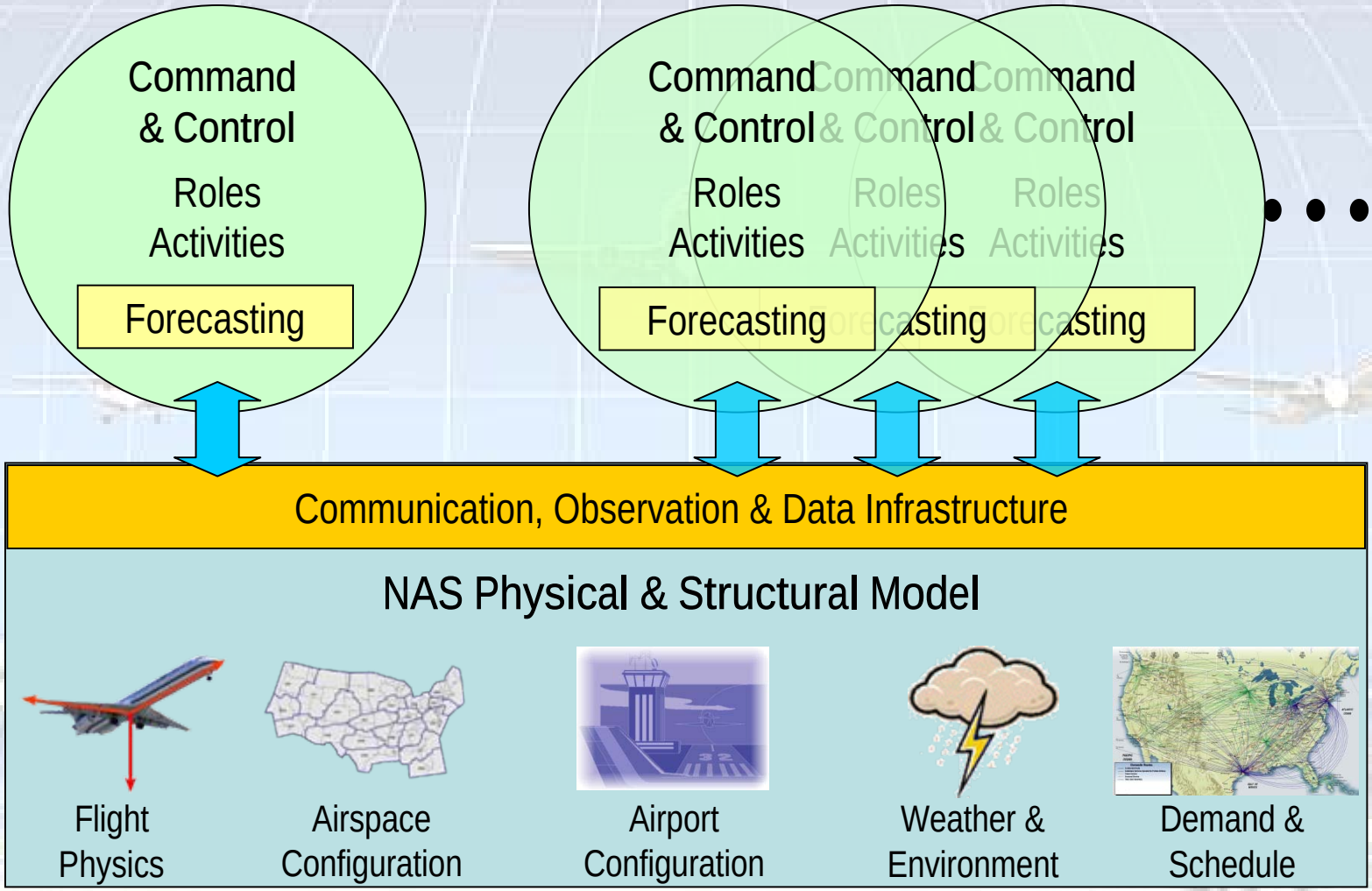
High Fidelity 4-DOF Trajectory Model

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

AwCNS

ACES Simulation Tool - Description/Overview

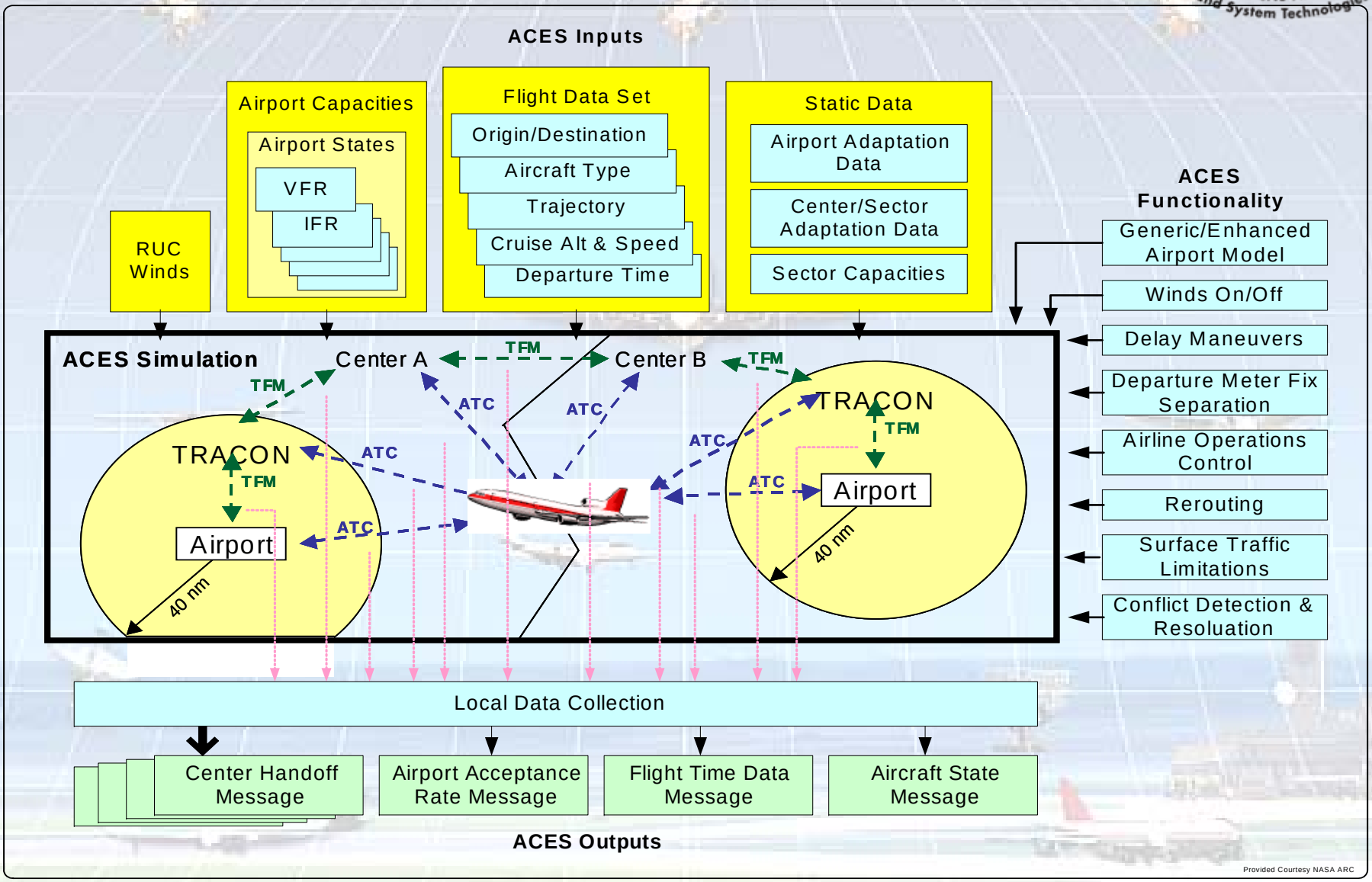
ACES Simulation and Modeling Approach



Courtesy NASA ARC

AwCNS

ACES Simulation Tool - Description/Overview



AwCNS

ACES to AwCNS

Integration of CNS Models/CNS Infrastructure into ACES

AwCNS (ACES with CNS Models)

Adds CNS Infrastructure operations into the ACES Simulation Environment

- Augments ACES with functional CNS System models.
- CNS Model enhancements added to create realistic ATM/CNS operations.
- CNS enhancements allow interactions between CNS Systems and Flight, ATC and ATM operations.
- AwCNS generates detailed CNS system performance data in NAS-wide, air traffic environment.
- Provides flexibility for integration of new models (process already established).
- Fully configurable for Aircraft/CNS equipage and for varying CNS system operating parameters.
- Takes full advantage of all ACES functionality including NAS Entities and Flight Operations

AwCNS

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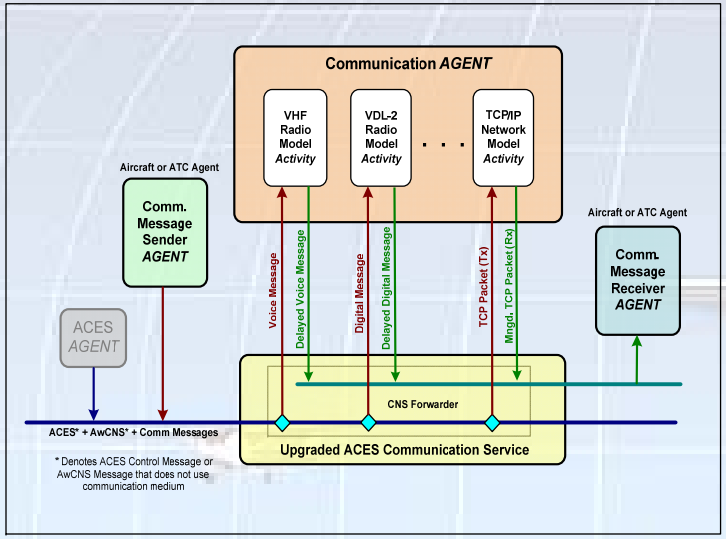
AwCNS Communication System Models Description

Voice over VHF Radio / CPDLC over VDL-2 Data link



Communication Model Description

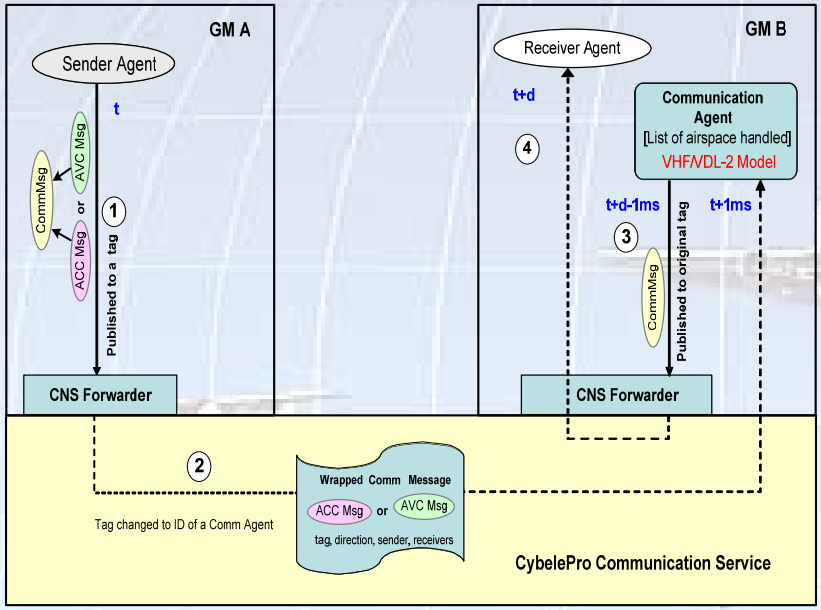
- VHF Radio propagation model for Voice Communication
- VDL-2 Data link model for CPDLC messaging
- Transmit common message sequences that occur. (ATC-to-A/C and A/C-to-ATC)
- Provide Radio protocols, link characteristics, interference.
- Use GS's mapped in CONUS for message delivery.
- Determine successful message delivery or retransmissions.
- Log message content, message duration and delays, retransmission data, radio channel utilization, message failure info, timestamps, other stats.

Voice and CPDLC Simulation Features

- Simulate message sequences between Controllers and Aircraft for all Phases of flight.
- Message sequences are initiated by NAS events on a per-Aircraft basis.
- Message sequences are synchronized with ACES flight control operations and command and control.
- Radio equipage can be assigned on a per-Aircraft-type or per-Airline basis.
- CPDLC messages are transmitted that are synonymous with Voice Messages. Fallback to Voice.
- All Messages and Radio (Aircraft or Ground Station) characteristics are configurable.
- Voice Messages can initiate Aircraft maneuvering in the en-route airspace.

AwCNS Communication System Models Description

Message Transmission - Agent Based Implementation/Process



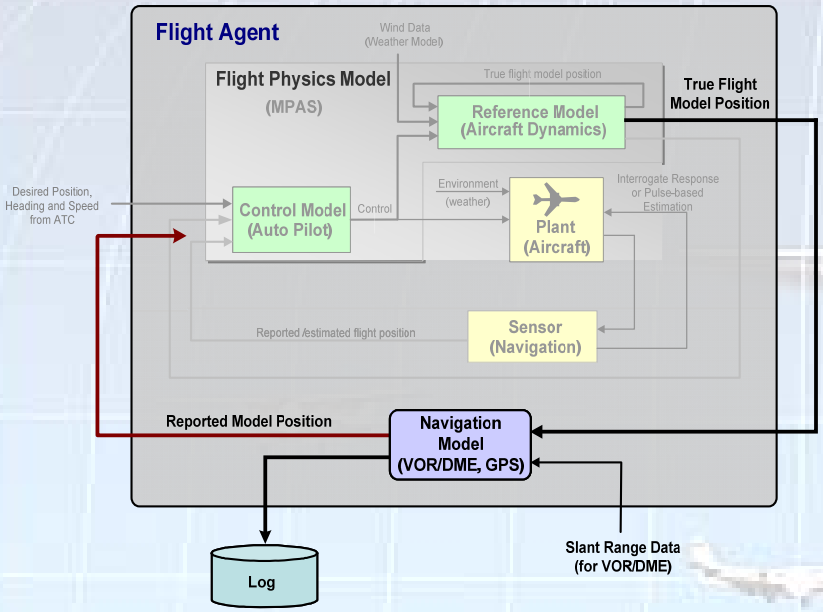
Voice and CPDLC Message Process

1) Message transmission initiated by an ACES event
2) Voice or Data link message sent by a Sender Agent (ATC or Pilot)
3) CNS Forwarder/Communication Service intercepts and re-Tags (wraps) each message for delivery to appropriate communication model.
4) Communication Model publishes the messages to the appropriate Receiver Agent
5) Receiver Agent receives message

- Message failure/retransmission is handled internal to the model.
- Messages within specific sequences require acknowledgement of previous message receipt

AwCNS Navigation System Models Description

GPS (w/selectable LAAS/WAAS) and VOR/DME - Navigation



Navigation Models Description

- Inherently onboard systems - implemented as Flight Agent (Aircraft) Activities
- Use ACES Flight Agent (Aircraft model) state message Latitude/Longitude as input.
- Statistical Models - output is statistically correct with error based on system characteristics

VOR/DME model – VOR ±1deg (StdDev .5 deg). DME uses Slant range for DME mean location - StdDev proportional to Slant Range location ± 2 deg)

GPS Model provides Standard, LAAS, WAAS StdDev = 3.15 m (Std), .91m (WAAS) and 3.1m (LAAS)

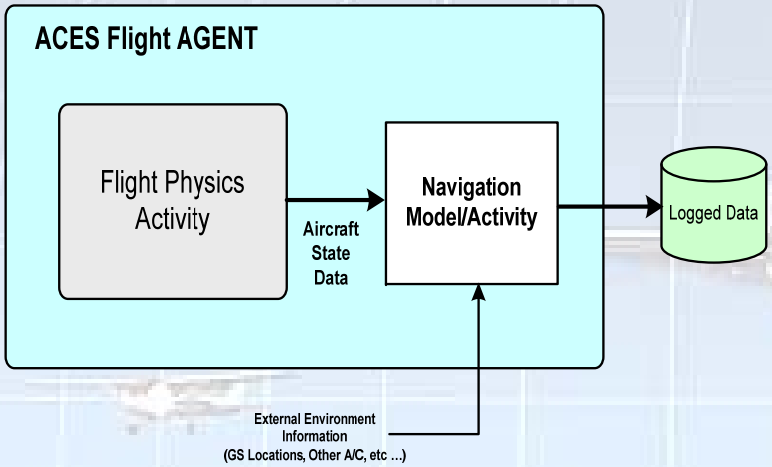
- Logs Reported Position, slant range (VOR/DME) and timestamp as output.

Navigation Simulation Features

- Provides statistically correct position deviations from ACES True positions.
- GPS or VOR/DME systems are selectable on a per-Aircraft-type or per-Airlines basis
- GPS can be configured to use LAAS/WAAS in Terminal/En-route airspace
- Closed-loop Navigation can be enabled to add the influence of Navigation system as Pilot/Autopilot adjustments to a simulation.
- Closed loop operation can influence ACES actions/responses to flight dynamics

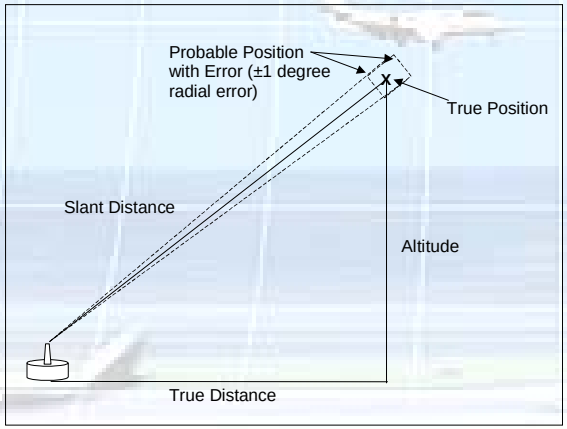
AwCNS Navigation System Models Description

Agent Based Implementation/Process



Navigation Message Process in ACES

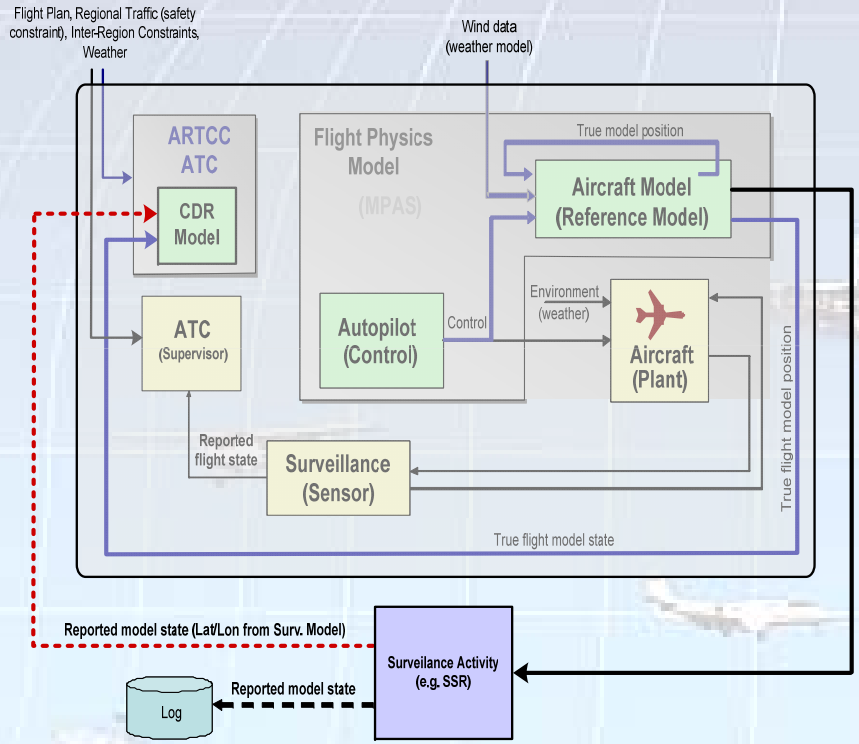
- Navigation Models Receive input (Lat/Lon) by subscribing to ACES Flight Agent, State messages. (true Lat/Long)
- For VOR/DME input is provided for Ground Station locations for Slant Range determination
- New reported position statistics logged in output data files



VOR/DME Position Error

AwCNS Surveillance System Models Description

Secondary Surveillance Radar Model



Secondary Surveillance Radar Model

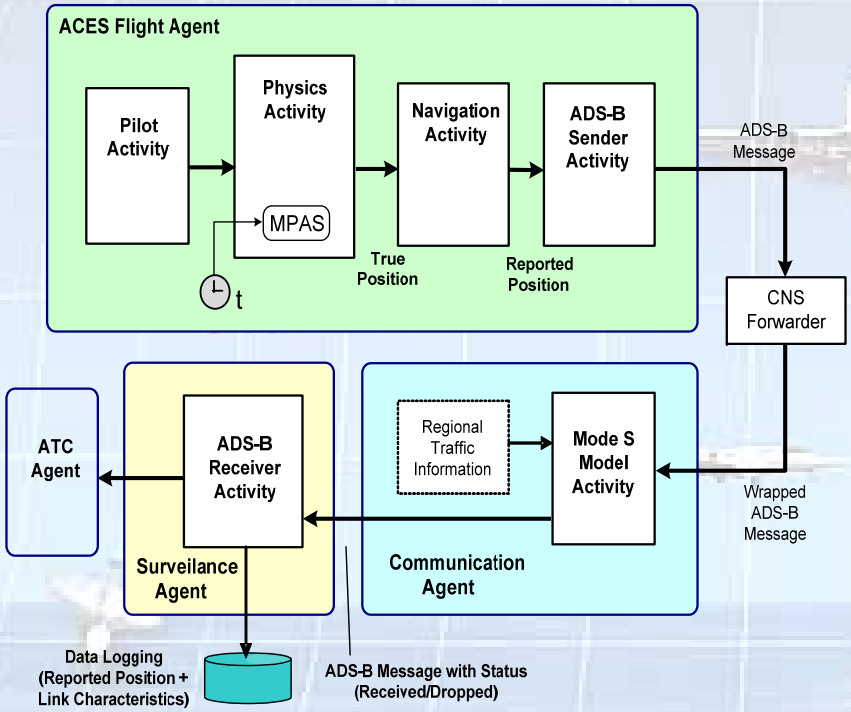
- SSR Model receives ACES Aircraft model True Position - generates new Reported Position
- SSR Model is a Statistical model – representative of a 5 rev/min en-route site
- Provides deviations due to Radar Precision (±1/8 nmi), Smoothing and Display Delay
- Logs data with per/flight, per/position measurement
- Closed Loop Operation

Surveillance Simulation Features

- Surveillance System (SSR or ADS-B) can be enabled on an Aircraft-type/Airline basis in a simulation
- SSR Surv. can operate Closed Loop for ATC decision-making response to reported position

AwCNS Surveillance System Models Description

Automatic Dependent Surveillance - Broadcast (Air to Ground) Model

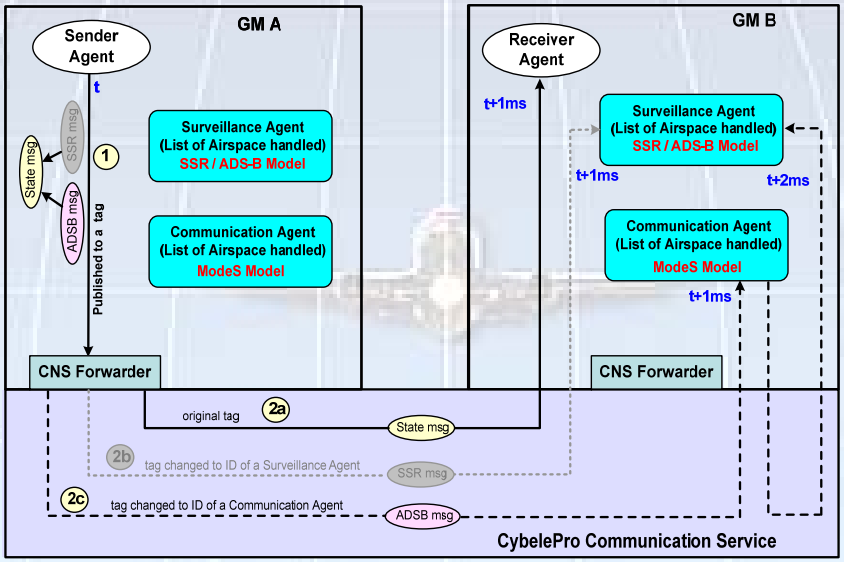


ADS-B Model

- Uses Nav. and Comm models for operation
- GPS or VOR/DME Model output used as its input position.
- ModeS (extended squitter) Model for A-G transmission
  - Delivers ADSB Messages 1/sec – propagation/delivery-probability model)
- Takes into account regional air traffic for interference
- Uses standard ADSB message size for transmission via the ModeS model.
- TCAS, ATCRBS and ADSB Long Message traffic is also represented in ModeS data stream
- Logs ADS-B model outputs: Position, Speed, Heading and Altitude + message delivery success rate info

AwCNS Surveillance System/Models Description

SSR and ADS-B (Air to Ground) Model Implementation



SSR Surveillance Message Process

1) State message published by Flight Agent (Sender)

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

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

ADS-B Message Process in ACES

1) ADS-B Model receives data from Nav Model used for the flight (as configured for the simulation).

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

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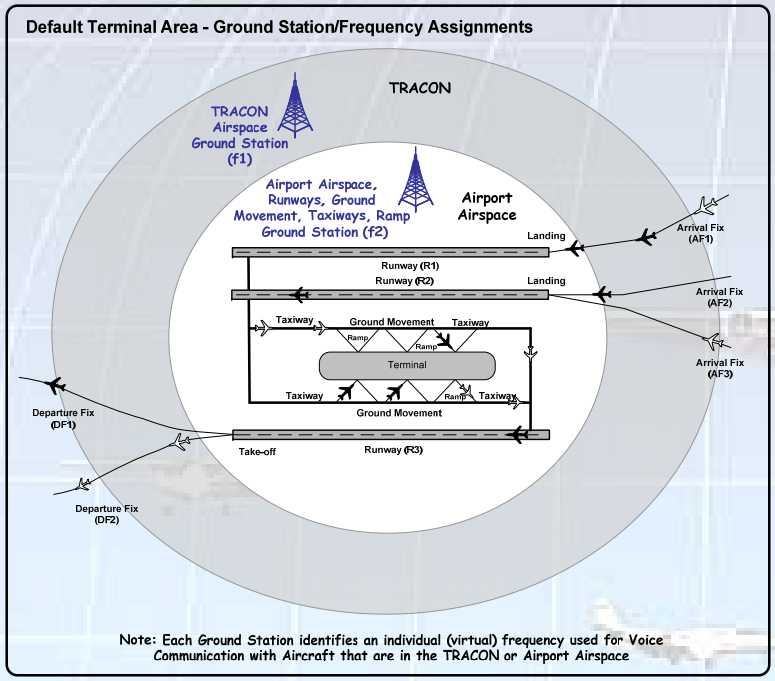
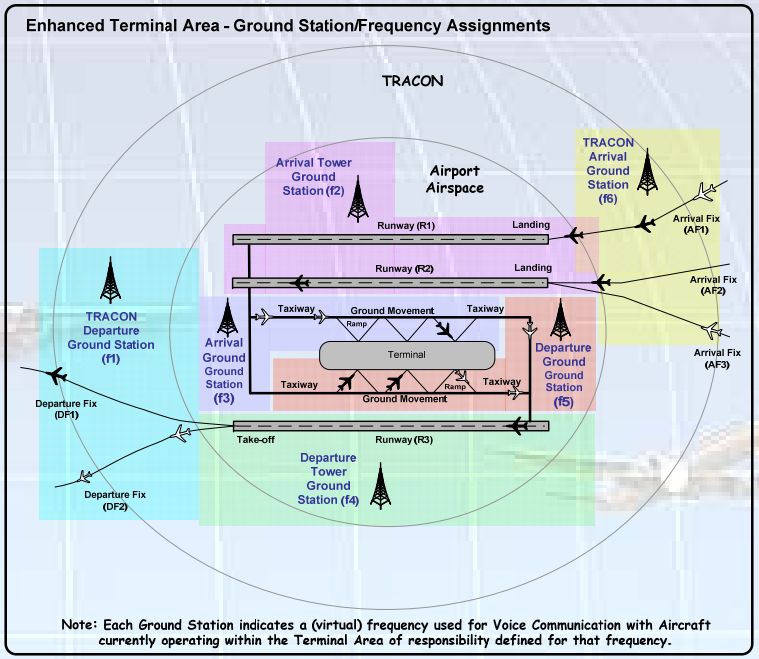
AwCNS Enhanced Capabilities – Extended Frequency Assignments





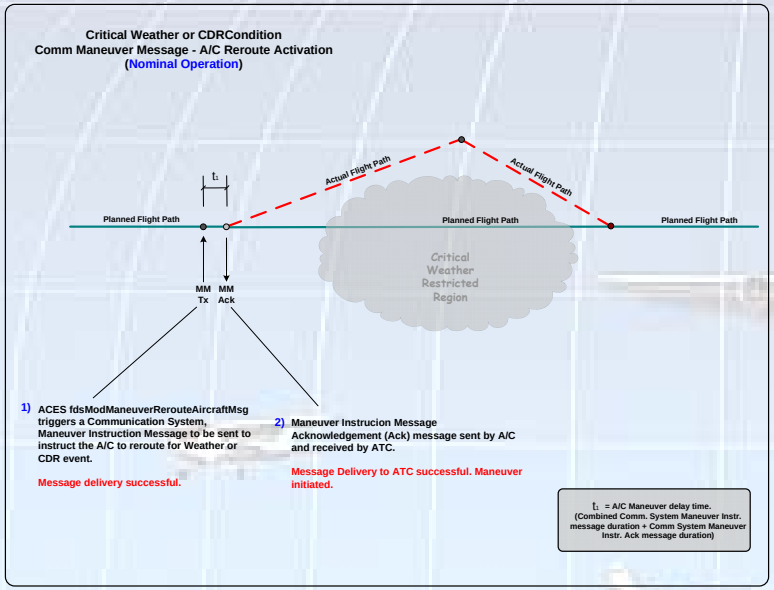
Default Airport Airspace Frequency Assignments

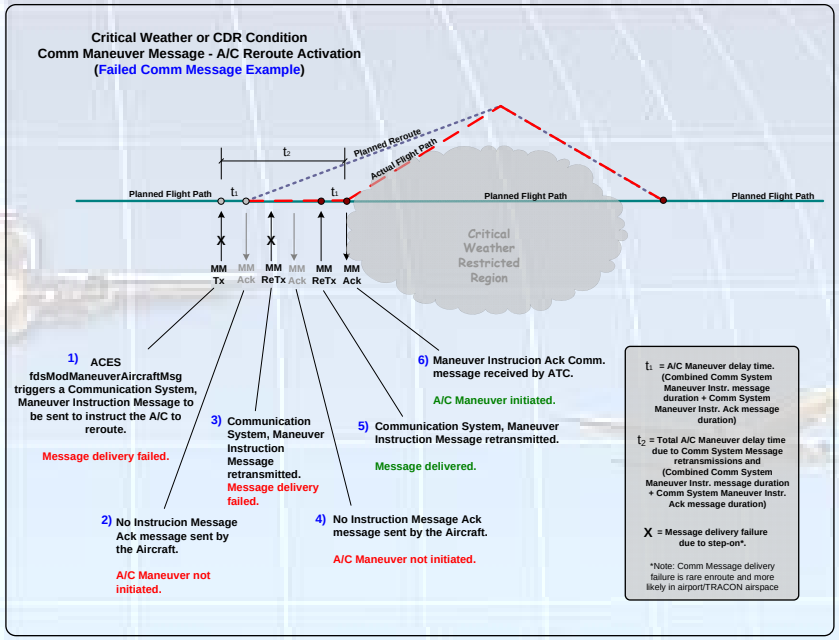
- Two Radio Towers used as VHF radio frequencies/channels at each airport
  (1 Airport, 1 TRACON)
- Baseline approach - sufficient for simulation purposes

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 - Voice Communication Activated Maneuvers





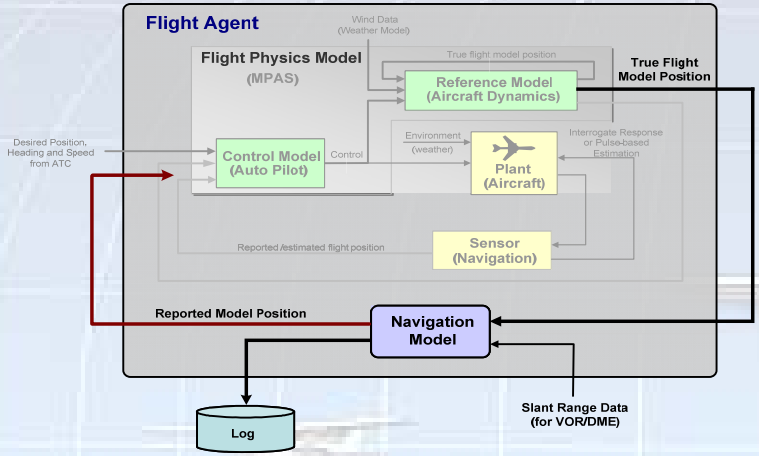
Communication Message Activated Maneuver (Default Operation)

- 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 (Message Retransmissions Required)

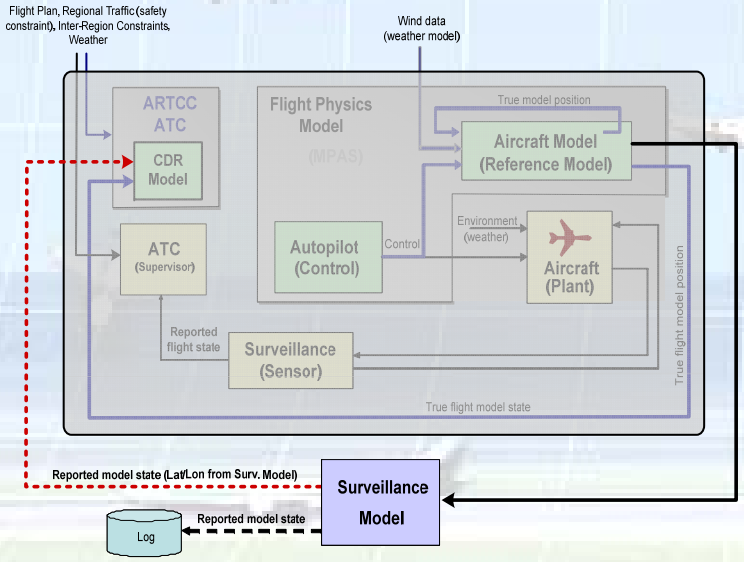
- Voice instruction or acknowledgement for maneuver requires retransmission due to step-on or interference
- Delays the aircraft from receiving the instruction for the maneuver

Enhanced Capabilities – Navigation and Surveillance Closed Loop



Navigation System Position Feedback to Aircraft

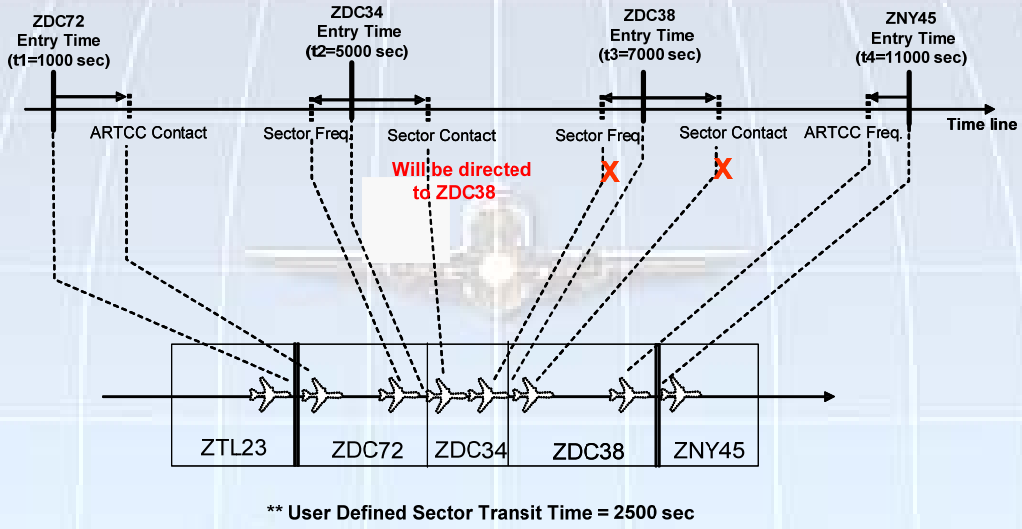
- Provides non-ideal position to Flight Agent from Navigation model.
- Provides the effect of a non-ideal flight path on flight times for fuel consumption evaluations or spacing for separation studies. (Pilot/autopilot – view).
- Could be most useful in congested airspace



Surveillance System Position Feedback to ATC

- 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.

Enhanced Capabilities – Short Sector Transition Frequency Handoff



** User Defined Sector Transit Time = 2500 sec

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

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AwCNS – General Configuration Capabilities

Varied Simulation Configurations can be applied to evaluate NAS Operations and CNS Systems Performance/Impact.

All Models and Interactions with ACES were developed to be 'as configurable as possible'

- CNS Operations can be enabled/disabled independently in a simulation. (C, N or S – on/off)
- Aircraft equipage for CNS systems can be varied using Configuration Files or GUI.
- Voice and CPDLC Communication messages can be varied for duration, bit length, message initiation, number of retransmissions.
- Onboard and GS Radio model characteristics (i.e. Tx/Rx power, Tx/Rx Sensitivity, etc, …) can be varied for all modeled radio types.
- VDL-2 Radio protocol timing parameters are able to adjusted via configuration file settings.
- Ground Station locations can be modified to experiment with varied GS topologies.
- Simulation of C, N or S system operation is selectable by Region, Sector, TRACON.
- Flights/flight paths controlled by user defined Flight Data Sets.
  (Simulations can be run with one to thousands of aircraft).
- All ACES capabilities are completely intact for simulations. Therefore all ATM and Control operations simulated in ACES can be exploited in an AwCNS simulations.

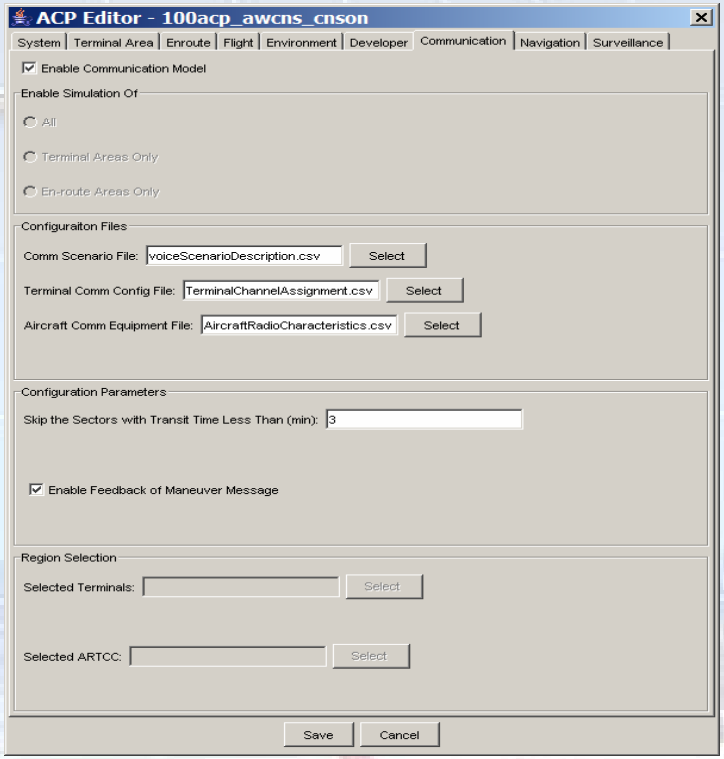
Models / Simulation Configuration

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.



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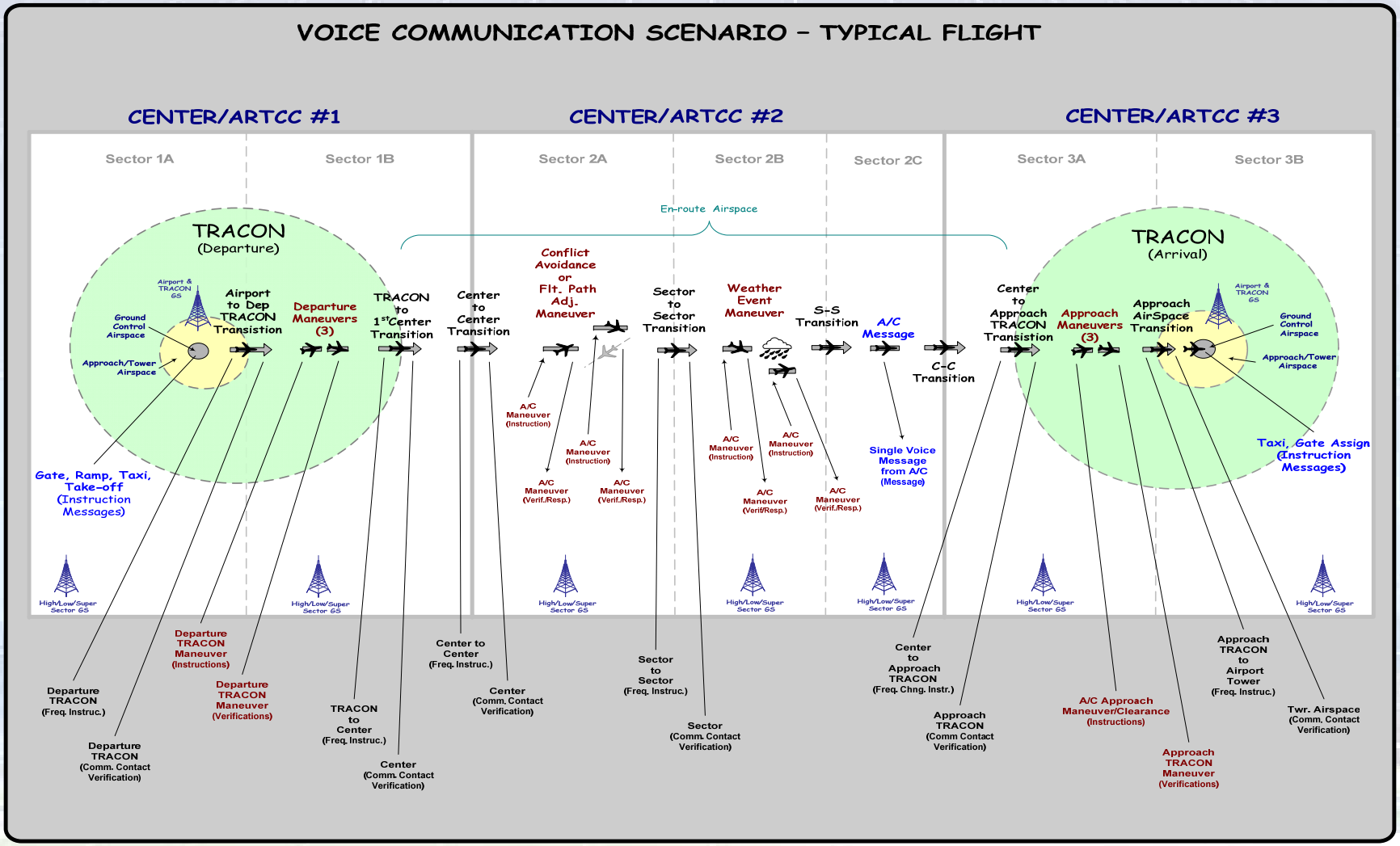
AwCNS Communication System Models Description

Voice/CPDLC Gate-to-Gate Messages



AwCNS

Simulation Results

IAD to SEA Demo Flight – Depature TRACON to En-route Airspace

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 Airspace to Depature TRACON	18	1	FlightAscentActivity	1116447209000		Flight2	AtoG	TKIAD
		3	VoiceCommunicationActivity	1116447213001	1	CommunicationAgent.TRACON.TKIAD	AtoG	TKIAD
	19	1	TerminalDepartureActivity	1116447213002		TraconAtc.TKIAD	GtoA	TKIAD
		6	VoiceCommunicationActivity	1116447227003	1	CommunicationAgent.TRACON.TKIAD	GtoA	TKIAD
	20	2	FlightAscentActivity	1116447227004		Flight2	AtoG	TKIAD
		9	VoiceCommunicationActivity	1116447232005	1	CommunicationAgent.TRACON.TKIAD	AtoG	TKIAD
Departure TRACON Maneuver Messages	64	2	TerminalDepartureActivity	1116447397360		TraconAtc.TKIAD	GtoA	TKIAD
		12	VoiceCommunicationActivity			N.TKIAD	GtoA	TKIAD
	65	3	FlightAscentActivity				AtoG	TKIAD
		15	VoiceCommunicationActivity			N.TKIAD	AtoG	TKIAD
	64	3	TerminalDepartureActivity				GtoA	TKIAD
		18	VoiceCommunicationActivity			N.TKIAD	GtoA	TKIAD
	65	4	FlightAscentActivity				AtoG	TKIAD
		21	VoiceCommunicationActivity			N.TKIAD	AtoG	TKIAD
	64	4	TerminalDepartureActivity				GtoA	TKIAD
		24	VoiceCommunicationActivity			N.TKIAD	GtoA	TKIAD
	65	5	FlightAscentActivity				AtoG	TKIAD
		27	VoiceCommunicationActivity	1116447515785	1	CommunicationAgent.TRACON.TKIAD	AtoG	TKIAD
A/C transition from Departure TRACON into first Center - ZDC (ie Enroute Airspace)	21	5	TerminalDepartureActivity				GtoA	TKIAD
		30	VoiceCommunicationActivity			N.TKIAD	GtoA	TKIAD
	22	6	FlightAscentActivity				AtoG	TKIAD
			VoiceCommunicationActivity			N.TKIAD	AtoG	TKIAD
Enters 1st Center								
	23	2	FlightEnRouteActivity				AtoG	ZDC05
		3	VoiceCommunicationActivity			C.ZDC	AtoG	ZDC05
	24	1	CrossingActivity.ZDC				GtoA	ZDC05
		6	VoiceCommunicationActivity			C.ZDC	GtoA	ZDC05
	25	3	FlightEnRouteActivity				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
			iceCommunicationActivity	1116448224785	1	CommunicationAgent.ARTCC.ZDC	AtoG	ZDC05
Enters Next Sector								
	28-1	5	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

18	DepartureTRACONContactRequestMessage
19	DepartureTRACONRadarContactWithInstructionMessage
20	DepartureTRACONRadarContactWithInstructionAckMessage
64	DepartureManeuverMessage
65	DepartureManeuverAckMessage
21	FirstARTCCFrequencyInstructionMessage
22	FirstARTCCFrequencyInstructionAckMessage

23	FirstARTCCContactRequestMessage
24	ARTCCRadarContactWithInstructionMessage
25	ARTCCRadarContactWithInstructionAckMessage
26	SectorFrequencyInstructionMessage
27	SectorFrequencyInstructionAckMessage

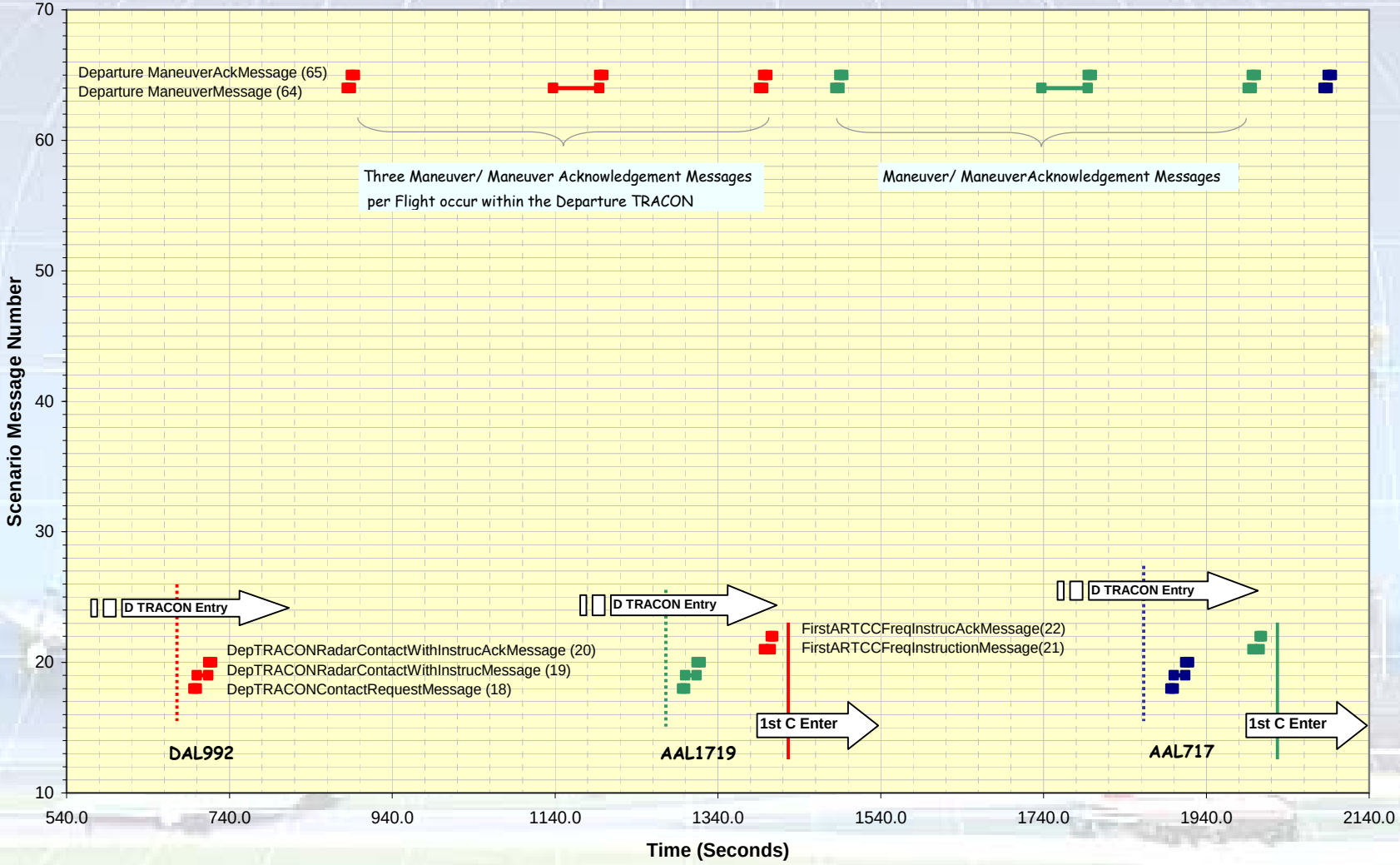
28	SectorContactRequestMessage
29	SectorRadarContactMessage

AwCNS

Simulation Results

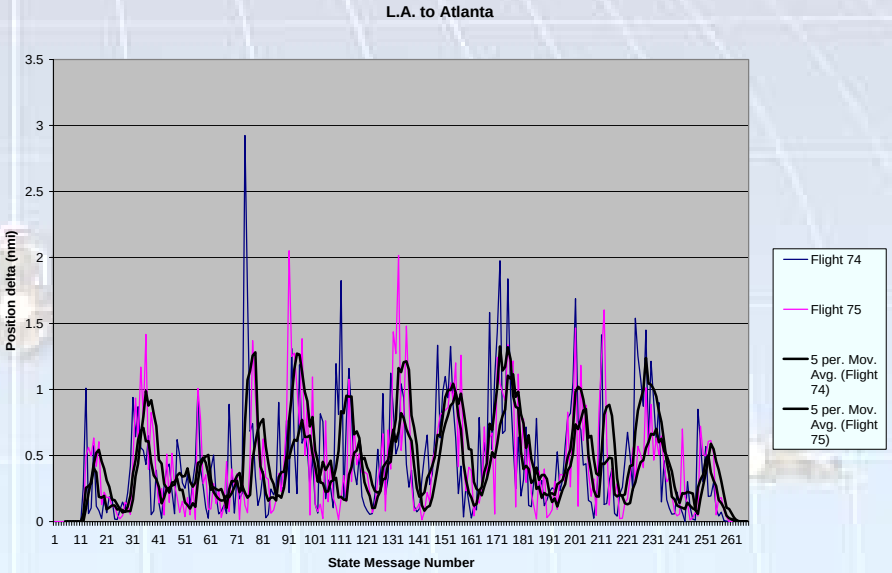
Voice Communication Characterization

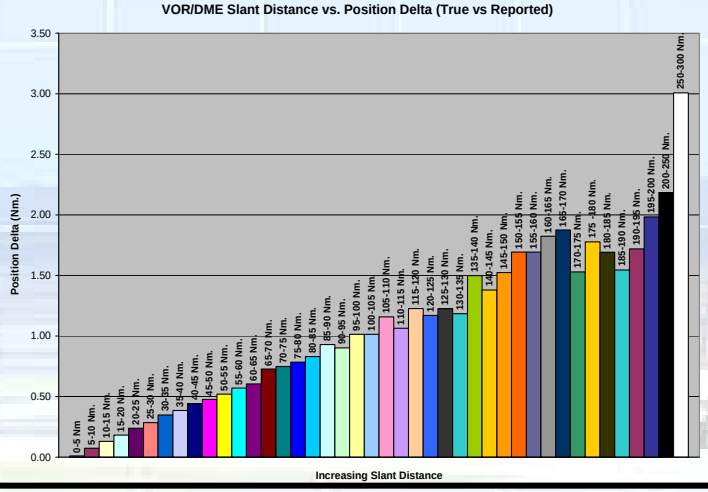
Dallas Fort Worth - TRACON Messages (Flights DAL992 / AAL1719 / AAL717)



Navigation (VOR/DME) Characterization Test Results

- 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





AwCNS

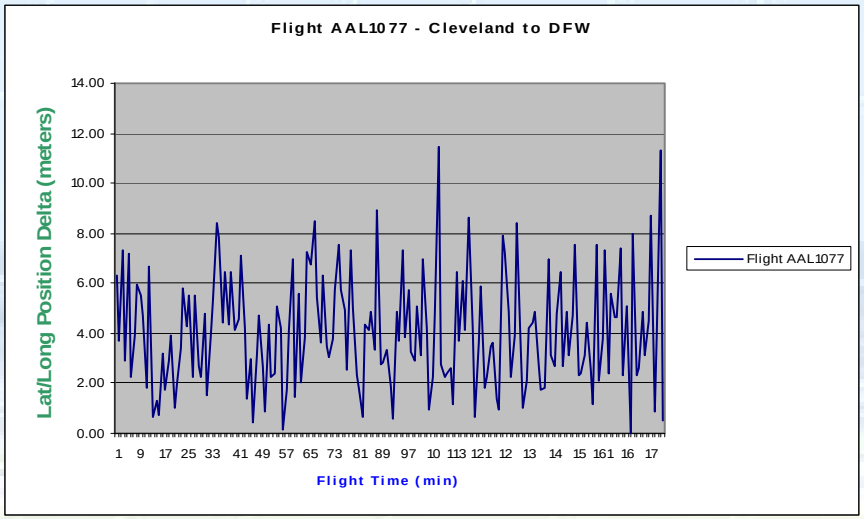
Navigation Models – GPS Characterization

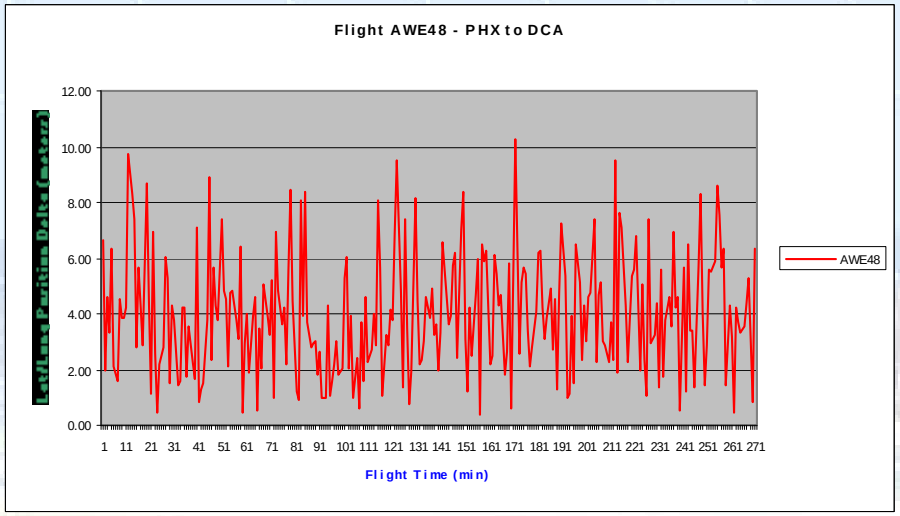
Verified that the GPS Model provides distinct difference in the position Latitude, Longitude and Altitude information. Table below indicates True vs. Reported data for 10 randomly selected data points for different flights in the 122flight FDS used for the test case.

flight Number	simulationTime	reported latitude	true_latitude	Delta Latitude	reported longitude	true longitude	Delta Longitude	Distance Between (nmi)	Equipment Type	LAASWAAS Enabled	Facility ID	nas Facility ID
AAL1077	1116446460001	41.41092756	41.4108889	0.00003867	-81.84942912	-81.84938889	-0.00004023	0.003392868	GPS	FALSE	KCLE	KCLE
AWE594	1116446640001	33.67565779	33.67563889	0.000019	-117.8682709	-117.8682222	-0.000049	0.003094528	GPS	FALSE	KSNA	KSNA
COA1726	1116451320001	41.47695041	41.4769271	0.00002335	-84.44634719	-84.44636298	0.00001579	0.00181054	GPS	FALSE	ZOB	ZOB
DAL1729	1116453060001	41.435					0.000004	0.001446505	GPS	FALSE	ZLC	ZLC
DAL470	1116449940001	33.802					-0.000037	0.002135738	GPS	FALSE	ZTL	ZTL
NWA1474	1116453960001	39.797					-0.00004130	0.002413251	GPS	FALSE	ZID	ZID
NWA28	1116458520001	44.51603575	44.51599525	0.000040	-95.6440848	-95.64407982	-0.000005	0.002811706	GPS	FALSE	ZMP	ZMP
SWA367	1116453420001	35.59126301	35.59127983	-0.000017	-106.7733712	-106.7734024	0.000031	0.002103657	GPS	FALSE	ZAB	ZAB
UAL91	1116454080001	41.24250039	41.24246976	0.000031	-90.75298217	-90.75299509	0.000013	0.002222162	GPS	FALSE	ZAU	ZAU

Equipment Type = GPS

LAASWAAS Enabled = False implies Standard GPS accuracy





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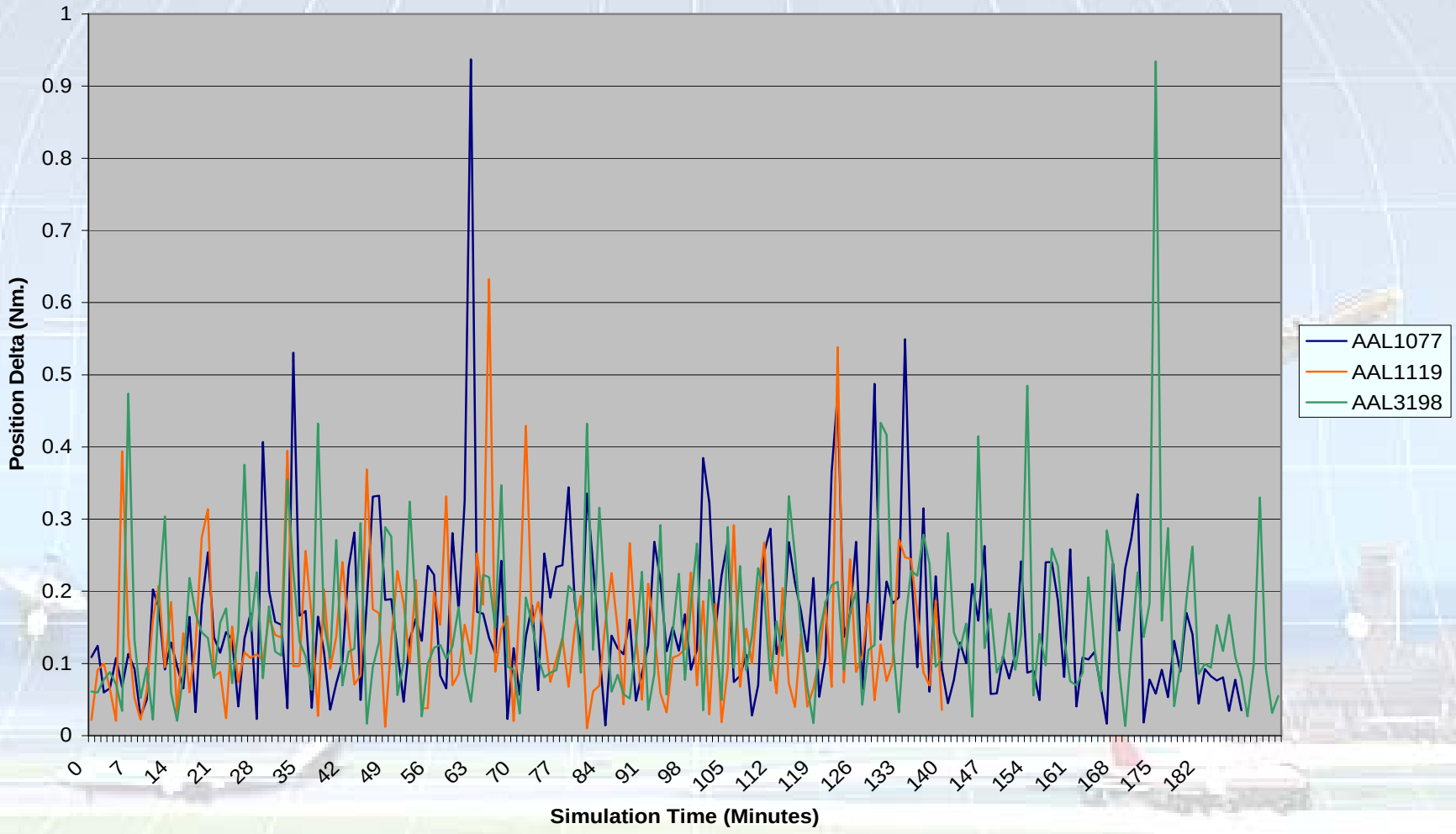
Surveillance (SSR) Characterization



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Enhancements

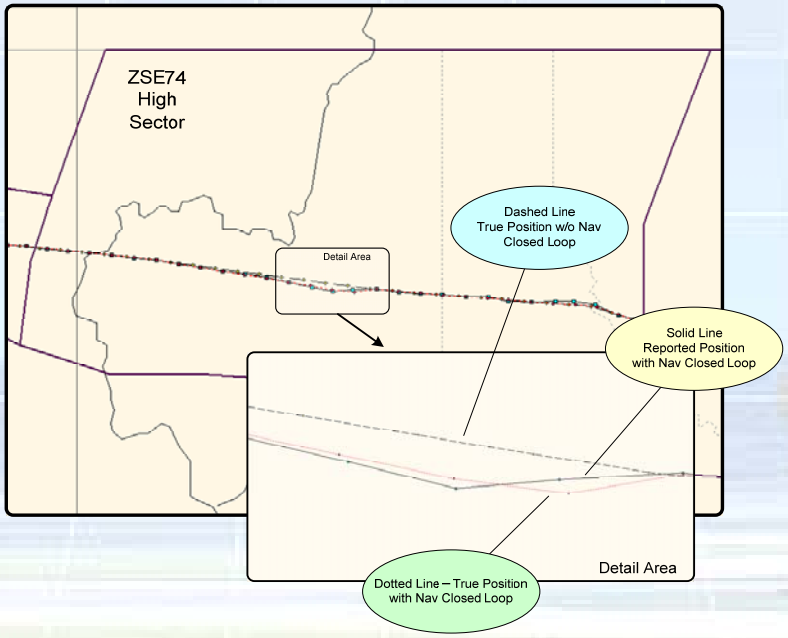
Navigation Closed Loop

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 flights, FDS (testing to see if flight durations lengthened)

- Average flight durations increased by 6.2 minutes

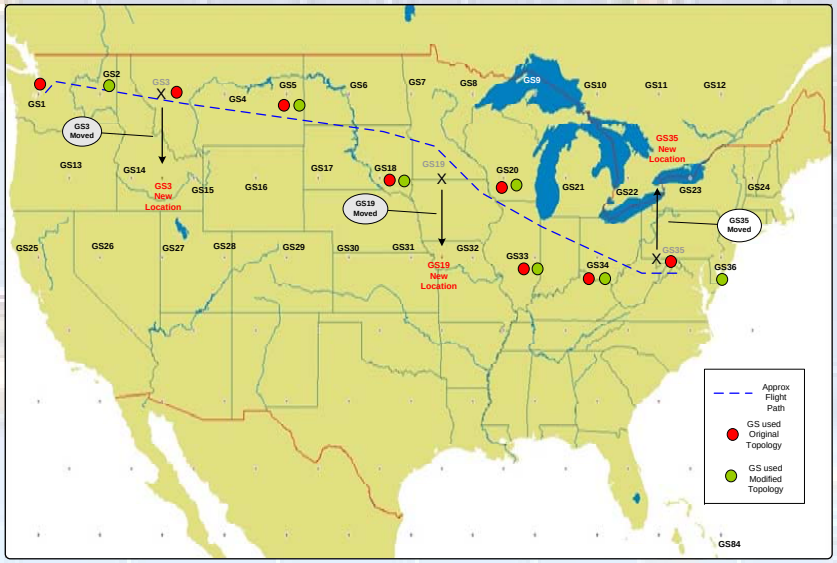


Model / Simulation Configuration

CPDLC VDL2 Ground Station Mapping Reconfiguration

Modified VDL2 Ground Station Topology file. resulted in different GS's being used for the VDL2 Comm link operation for CPDLC messaging. Graphically the changes are show in the illustration.

The table below shows information provided in the VDL2ChannelUtilizationStatistics file that identifies the GS used for each transmission for the nominal topology file and for the modified file.



				GS's at Modified Locations		GS's at Nominal Locations	
objectid	activityId	simulationTime	agentId	ground Station ChannelId	GS Utilization	ground Station ChannelId	GS Utilization
GM_1-0	VDL2Activity	1116446430000	CommunicationAgent.AIRPORT.KIAD	KIAD_0.0	0.0040000000	KIAD_0.0	0.0040000000
GM_1-26	VDL2Activity	1116447210000	CommunicationAgent.TRACON.TKIAD	TKIAD_1.36974E8	0.0013666666	TKIAD_1.36974E8	0.0013666666
GM_1-54	VDL2Activity	1116448050000	CommunicationAgent.ARTCC.ZDC	GS36_1.36975E8	0.0020666666	GS35_1.36975E8	0.0020666666
GM_1-82	VDL2Activity	1116448890000	CommunicationAgent.ARTCC.ZID	GS34_1.36975E8	0.0001666666	GS35_1.36975E8	0.0001666666
GM_1-139	VDL2Activity	1116450600000	CommunicationAgent.ARTCC.ZID	GS34_1.36975E8	0.0000000000	GS35_1.36975E8	0.0000000000
GM_1-186	VDL2Activity	1116452010000	CommunicationAgent.ARTCC.ZID	GS33_1.36975E8	0.0001666666	GS33_1.36975E8	0.0001666666
GM_1-261	VDL2Activity	1116454260000	CommunicationAgent.ARTCC.ZAU	GS20_1.36975E8	0.0003166666	GS20_1.36975E8	0.0003166666
GM_1-290	VDL2Activity	1116455130000	CommunicationAgent.ARTCC.ZMP	GS18_1.36975E8	0.0015666666	GS18_1.36975E8	0.0015666666
GM_1-358	VDL2Activity	1116457170000	CommunicationAgent.ARTCC.ZLC	GS5_1.36975E8	0.0002000000	GS5_1.36975E8	0.0002000000
GM_1-498	VDL2Activity	1116461190000	CommunicationAgent.ARTCC.ZSE	GS2_1.36975E8	0.0003166666	GS3_1.36975E8	0.0003166666
GM_1-548	VDL2Activity	1116462690000	CommunicationAgent.ARTCC.ZSE	GS2_1.36975E8	0.0003166666	GS1_1.36975E8	0.0015000000
GM_1-562	VDL2Activity	1116463110000	CommunicationAgent.TRACON.TKSEA	TKSEA_1.36974E8	0.0020666666	TKSEA_1.36974E8	0.0020666666
GM_1-584	VDL2Activity	1116463770000	CommunicationAgent.AIRPORT.KSEA	KSEA_0.0	0.0021666666	KSEA_0.0	0.0021666666

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)
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

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

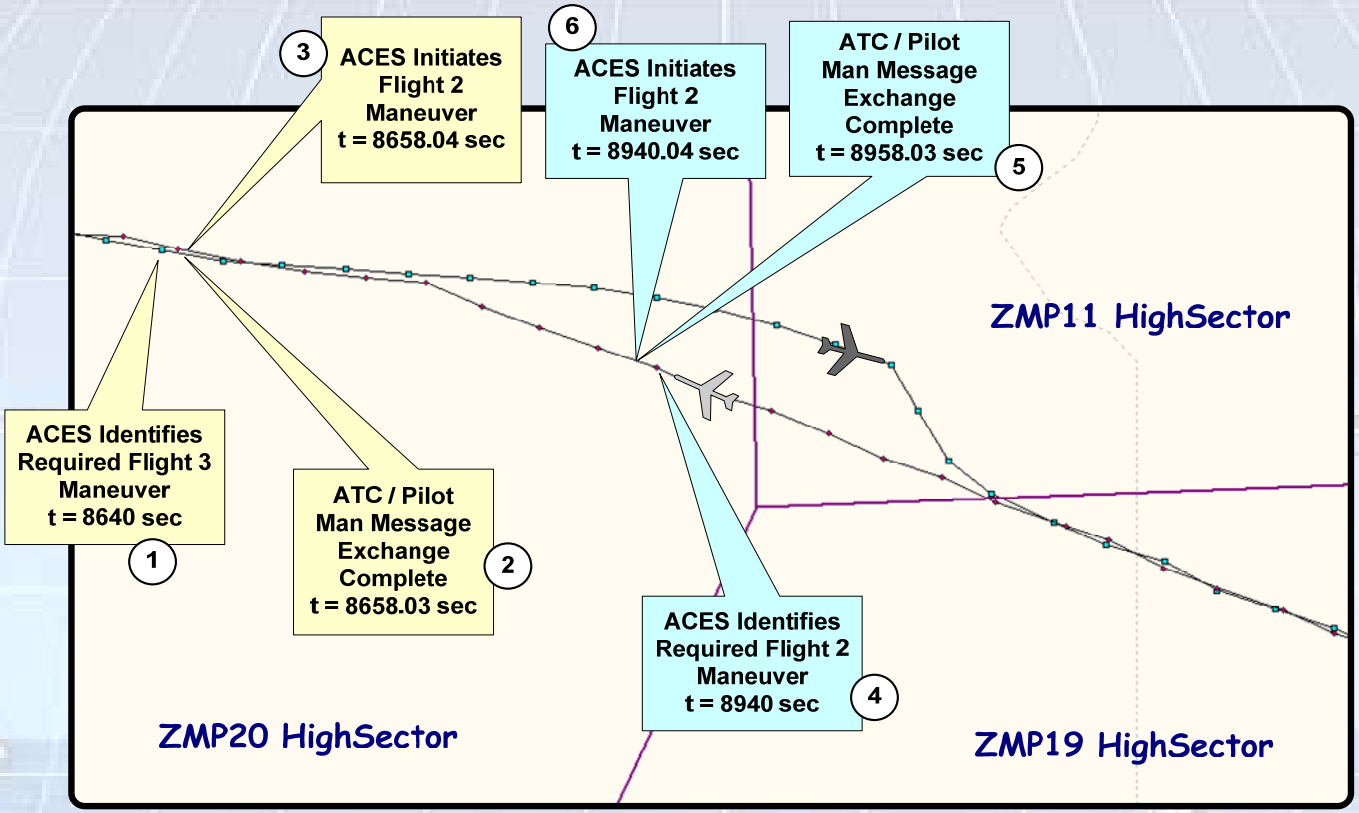
➢ Recorded the number of Congestion (Interference) Errors, Step-on Errors and Expired Transmissions (I.e. messages never sent)

➢ 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

Enhancements

CDR Maneuver – Communication Activated Maneuver



Results: Voice message sequences and subsequent aircraft maneuvering occurred as expected. Two ACES maneuvers occurred, one for black aircraft, one for gray aircraft. In both cases voice message delivered prior to initiation of the actual maneuver.

AwCNS

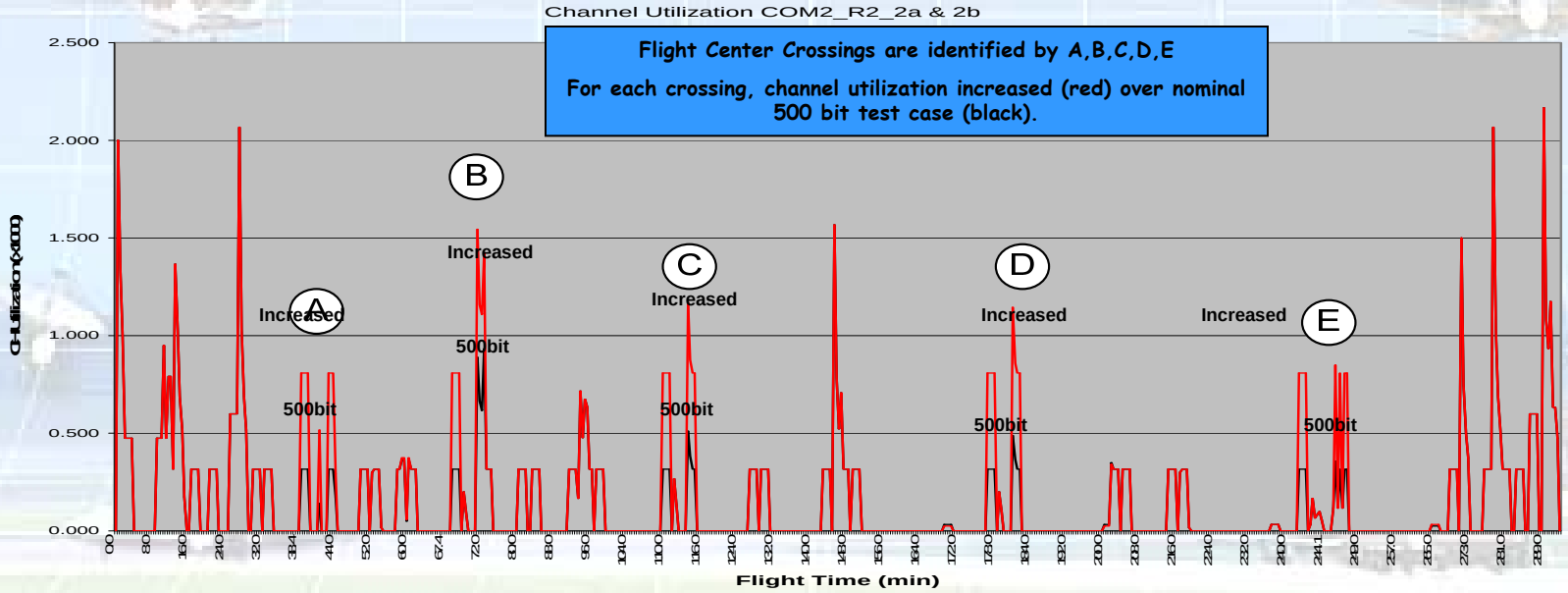
Model / Simulation Configuration

Modification to *CommScenarioDescription* File

Reconfiguration Scenario: Modified the CPDLC Message bit-length in the CommunicationScenarioDescription.csv file to verify the use of this parameter in a CPDLC Commuincation test case.

Center Crossing, Frequency Handoff Sequence message lengths increased from original 500 bits, to those shown here in Red

```
CNSSectorCont                                                    Flight XYZ: XYZ Center: roger; radar contact.,3,500,500

CNSARTCCFrequ                                                    _HANDOFF_PREPARTION,Flight XYZ: XYZ Center: contact Indianapolis Center now on one three
three point t                                                    freq = xxx.xx for Ind. Center),5,500,5000

CNSARTCCFrequencyInstructionAckMessage,FlightEnRouteActivity,C_C_HANDOFF_PREPARTION,Flight XYZ: roger; Indianapolis Center now on one three three
point three five; good-day. (A/C verifies instruction to use xxx.xx for Ind. Center),5,500,2000

CNSARTCCContactRequestMessage,FlightEnRouteActivity,ARTCC_CONTACT,Indianapolis Center: Flight XYZ is with you at flight level three niner zero.
(First communication with Ind. Center),3,500,5000

CNSARTCCContactAckMessage,CrossingActivity,ARTCC_CONTACT,Flight XYZ: Indianapolis Center: roger; flight level three niner zero.,3,500,2000

CNSManeuverMessage,ManeuverActivity,MANEUVER_C_C,Ind Center Instructs Flight XYZ to change elevation to 430,10,500,500

CNSManeuverAckMessage,FlightEnRouteActivity,MANEUVER_C_C,Flight XYZ verifies change to Flight level 430,8,500,500
```



- ACES Description/Overview
- AwCNS Models Description

  VHF Voice, CPDLC VDL-2, VOR/DME, GPS w/LAAS-WAAS, SSR and ADS-B
- AwCNS Enhanced Capabilities Description

  ORD/EWR Enhanced Frequency Assignments, Comm Activated Maneuvers Nav. and Surv. – Closed Loop Operation
- AwCNS Models and Simulation Configuration Capabilities
- Simulation Examples and Requirements Test Results
- **AwCNS Models Applicability to NAS Analysis**

AwCNS Applicability to NAS Evaluations

Communications

How can AwCNS Communication Sims be applied to NAS Evaluations?

- **Traffic Load vs. Air Traffic Controller Workload Assessments**
  i.e. What would be required of Traffic Controllers for varied Air traffic conditions?
- **Assess ATM Critical Event Reaction/Response Capability vs. Traffic Load**
  i.e. Can the Comm. System deliver critical messages for increased air traffic loads?
- **Evaluate current Voice System capability to accommodate increased Air Traffic with decreased separation**
  i.e. Will the ATC Workload or Voice System be overloaded?
- **Evaluate use of Mixed Mode (Voice + Datalink) to accomodate future traffic loads**
  i.e. How might future infrastructure concepts apply Mixed Mode Communications?

AwCNS Applicability to NAS Evaluations / Upgrades

Navigation

How can AwCNS Navigation Sims. be applied to NAS Evaluations?

- **Apply Navigation System Models to assess concepts designed to provide more efficient aircraft separation and spacing rules.**
  i.e. What would be required of Traffic Controllers with increased air traffic?
- **Apply Closed Loop Navigation to determine how improved Navigation systems could affect aircraft fuel consumption.**
  i.e. What kind of bucks$$ could be saved with improved navigation accuracy?
- **Apply Varied Navigation and/or Surveillance systems in closed loop operation to assess their effect on reported CDR events and TFM operations.**
  i.e. What safety improvements/efficiencies might be realized with new N or S systems?
- **Apply Closed Loop Navigation with Communication Activated Maneuvers to assess the use of new technologies for improved maneuver initiation with non-ideal maneuverability (especially in congested airspace).**
  i.e. What safety improvements could be realized with improved N and C systems?

AwCNS Applicability to NAS Evaluations / Upgrades

Surveillance

How can AwCNS Surveillance Sims. be applied to NAS Evaluations?

- **Evaluate Surveillance Systems simulations that compare performance for Separation and Spacing operations**

  i.e. How might separation/spacing standards be changed with improved surveillance?

- **Evaluate Surveillance Systems simulations that compare performance for Merging of aircraft**

  i.e. How could improved Surv. systems impact transitions of individual aircraft into airport traffic conditions?

- **Evaluate mixed Surveillance system equipage simulations to determine worst case scenarios for Separation/Spacing/Merging.**

  i.e. What impact will mixed equipage have on ATC operating standards?

- **Evaluate surveillance systems use in Airport/Terminal airspace for proposed new concepts for approach and airport/runway configurations**

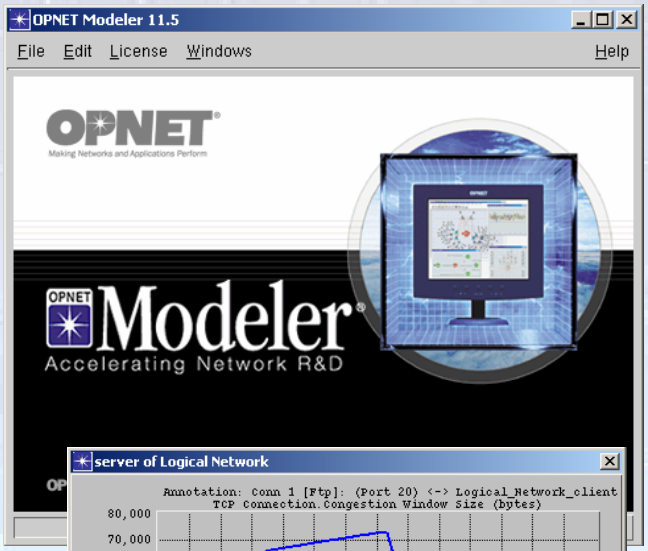
  i.e. Will new concepts be practical with perceived improvements to surveillance systems?

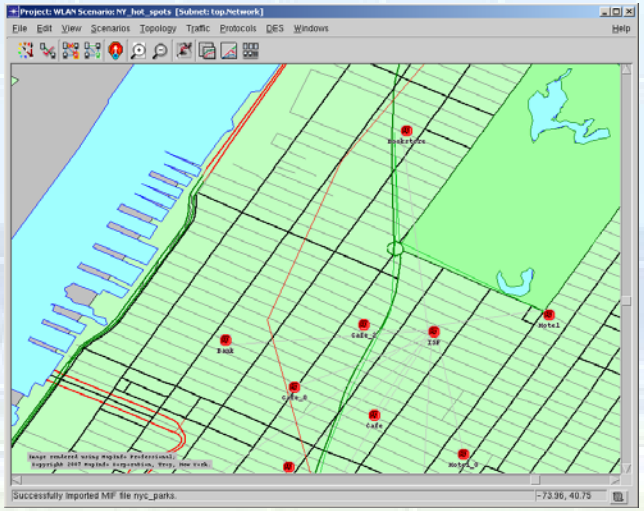
- Overview of NASA GRC Modeling, Simulation and Analysis Capabilities
  - ACES with CNS
  - OPNET
  - Other
  - Approach
- Some Simulation Examples
- Summary of Simulation Tools and CNS Models

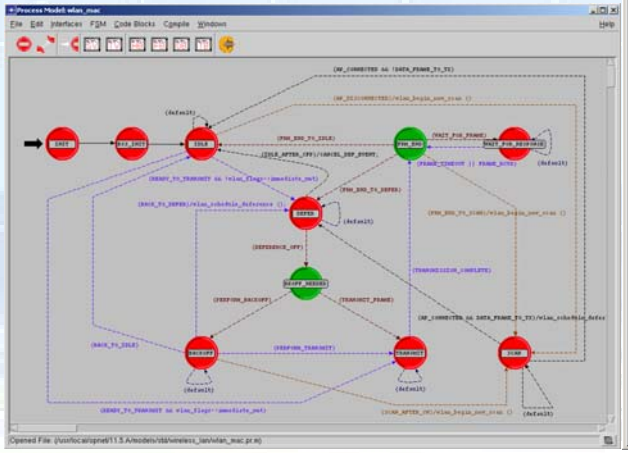
OPNET

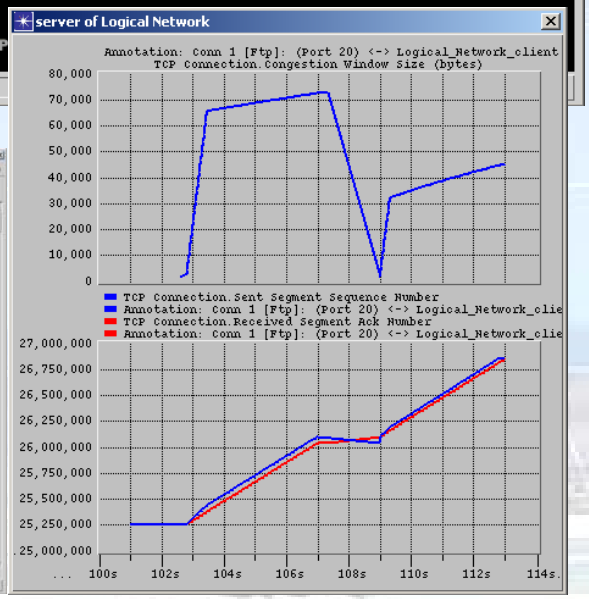
OPNET Overview

- OPNET Modeler is a discrete-event simulation package
  - Can be used to model
    - > Processes
    - > Protocols and Applications
    - > Devices
    - > Communications systems
  - Includes hundreds of protocols and devices
  - New protocols and devices can be created
- Modular design
- Supports fixed, mobile, and satellite nodes





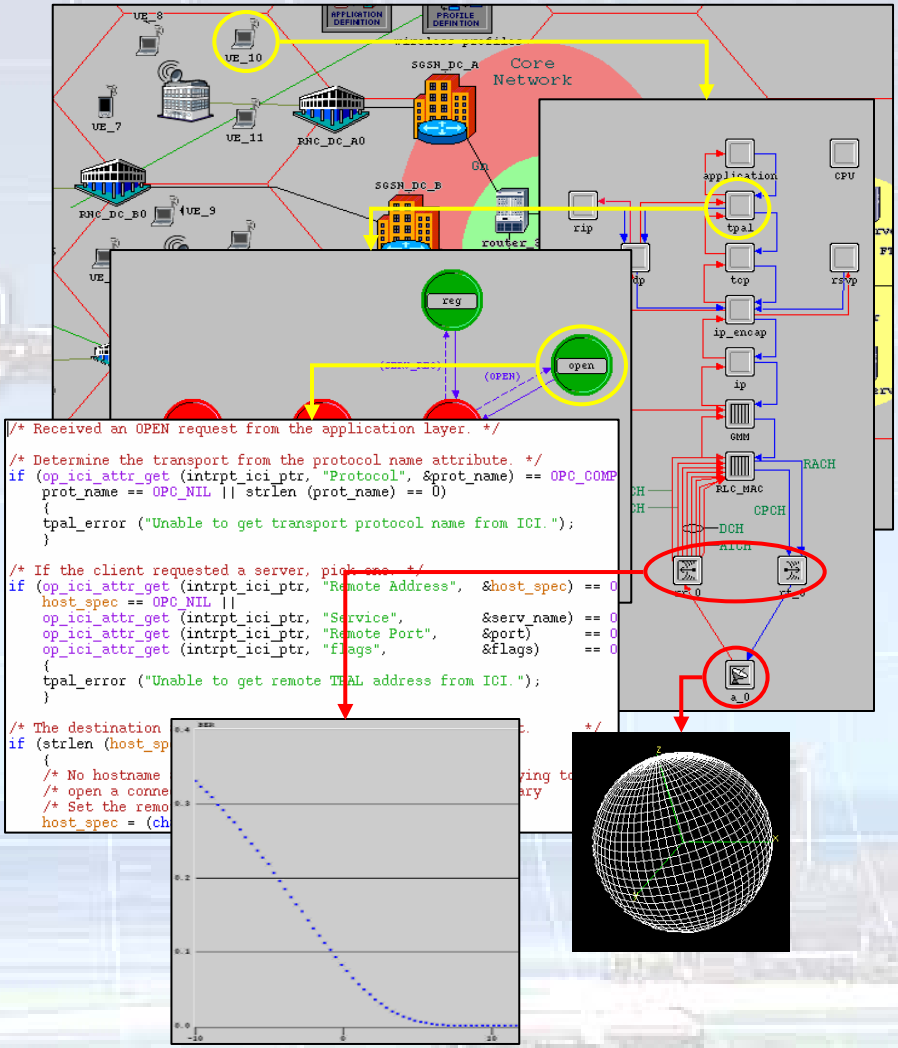




OPNET

OPNET Hierarchy

- Network model
  - Defines the topology and attributes of all simulation objects in 3-dimensional space
- Node Model
  - Defines a device or object as a set of processes and data flows
- Process Model
  - Finite state machine that describes the functionality of a process
- Process Code
  - Provides the logic for each state of the FSM
- Channel Pipeline Model
  - Antenna parameters, modulation curves, and code model the propagation effects of the physical channel

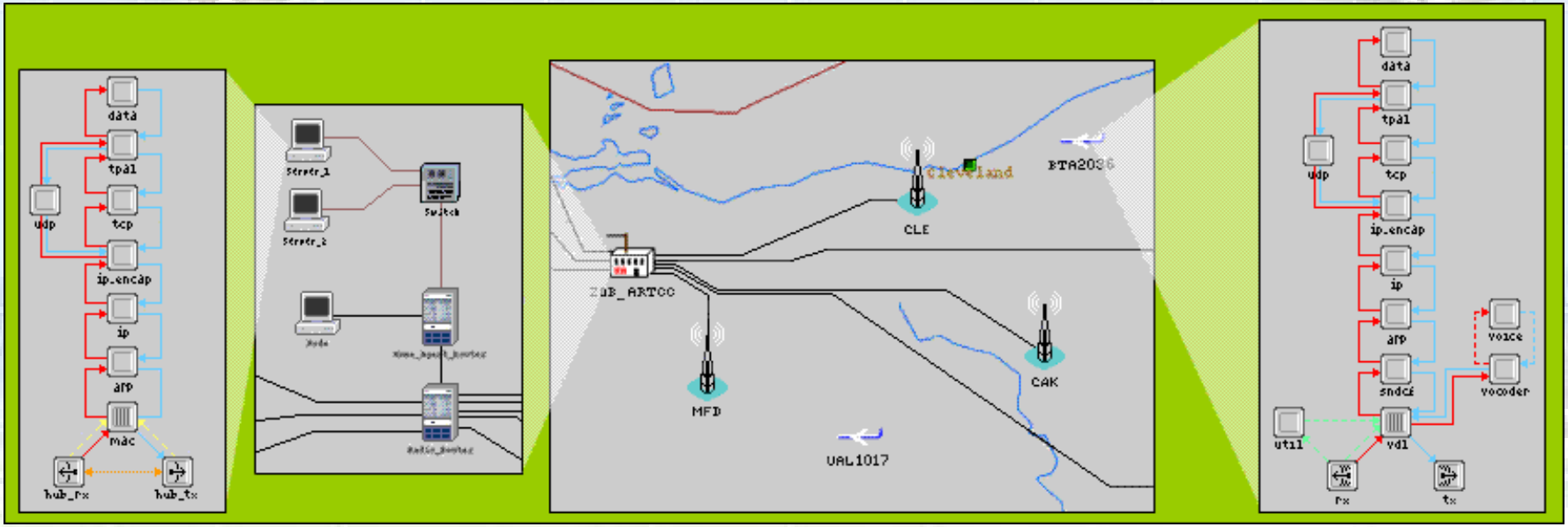


OPNET

OPNET Communications Example

- Simple network scenario composed of:
  - Aircraft
  - Radio Communications Ground Stations
  - ARTCC made up of routers and servers
- End-to-end path includes effects due to:
  - Protocol functionality
  - Network load and queuing delays
  - Transmission and propagation delays
  - Noise and collisions on wireless channel

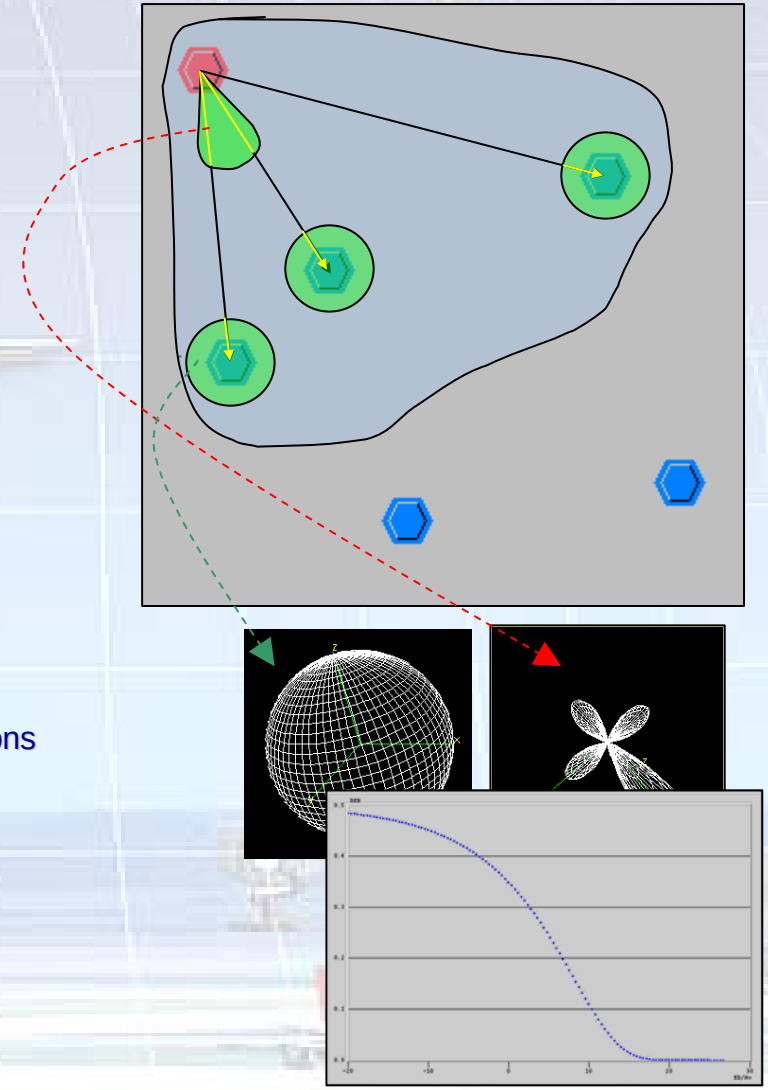
- Example Uses
  - Determine loading of devices, links, or channels
  - Find congestion point or capacity of a link or channel
  - Determine effects of interference
  - Compare technologies
  - Examine transitional phases between technologies
  - Investigate protocol modifications



OPNET

Channel Pipeline Stages

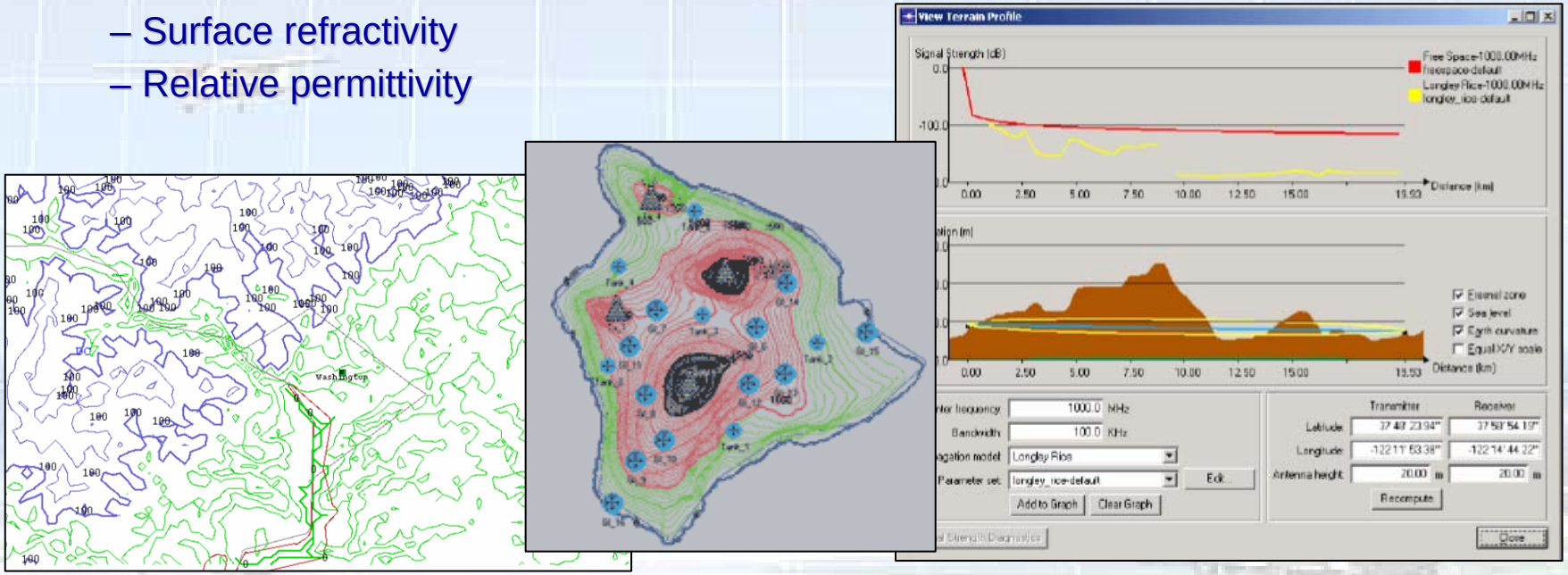
- Stage 1 - Transmission Delay
  - Calculates the time required to complete transmission
- Stage 2 - Link Closure
  - Uses line-of-sight to determine if signal can be recieved
- Stage 3 - Channel Match
  - Determines if transmitter and receiver properties allow reception
- Stage 4 - Transmitter Antenna Gain
  - Determines gain of transmit antenna in direction of receiver
- Stage 5 - Propagation Delay
  - Calculates propagation delay based on distance
- Stage 6 - Receiver Antenna Gain
  - Determines gain of receive antenna in direction of transmitter
- Stage 7 - Received Power
  - Calculates the received power based on distance and gains
- Stage 8 - Background Noise
  - Provides mechanism for addition of implicit background noise
- Stage 9 - Interference Noise
  - Determines interference due to simultaneously arriving transmissions
- Stage 10 - Signal to Noise Ratio
  - Calculates SNR based on received power and interference
- Stage 11 - Bit Error Rate
  - Determines BER based on SNR and modulation curve
- Stage 12 - Bit Error Allocation
  - Allocates bit errors from BER and length of message
- Stage 13 - Error Correction
  - Applies error correction if applicable



OPNET

OPNET TMM Model

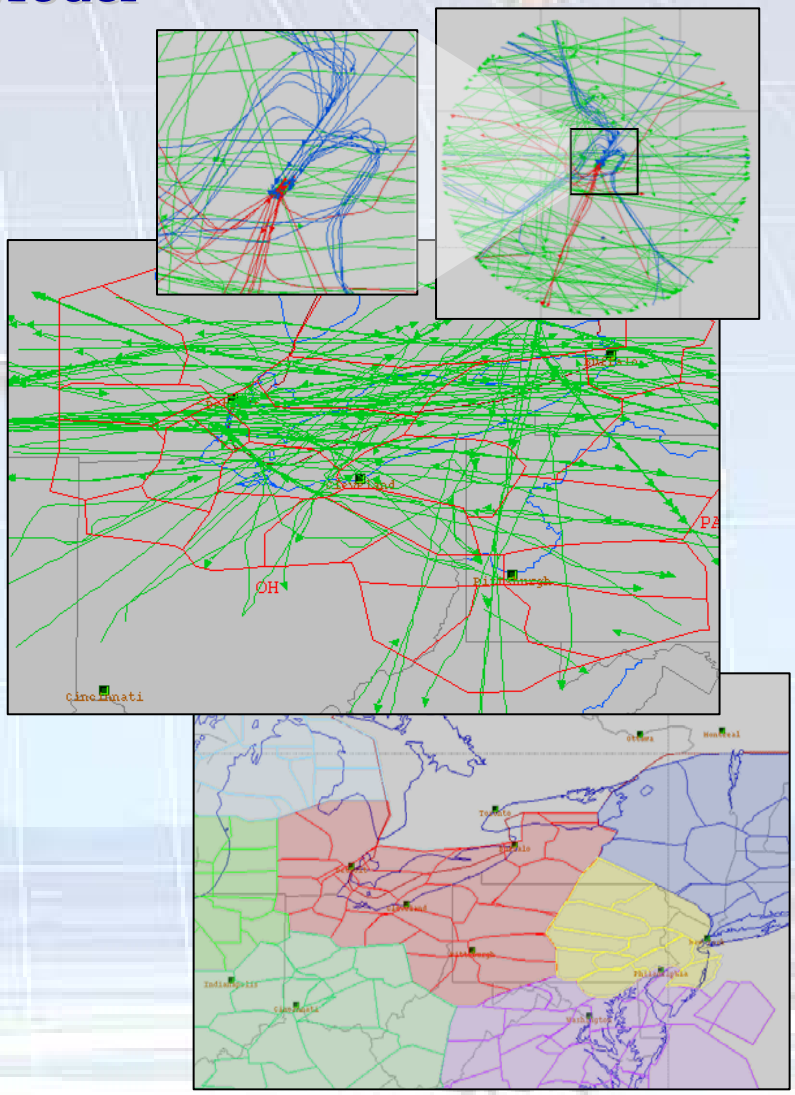
- Terrain Modeling Module (TMM) is an optional OPNET module that can be added to our simulation tools
  - Increases the accuracy of a simulation by taking into account signal loss due to terrain effects
- Uses physical features and environmental factors to determine path loss
  - Curvature of the earth and landscape (mountains, valleys, etc)
  - Ground conductivity
  - Surface refractivity
  - Relative permittivity



OPNET

OPNET Airspace Model

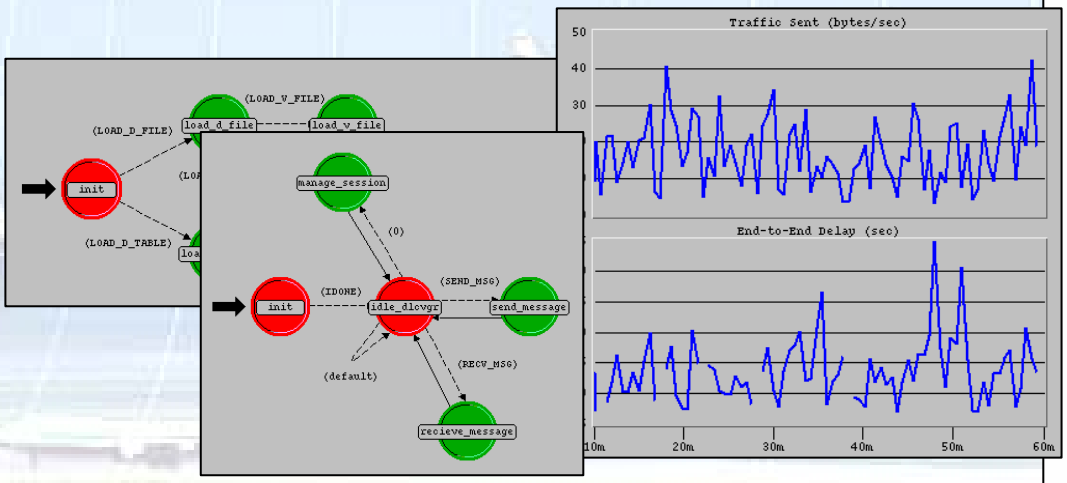
- Airspace model divides 3-dimensional space into centers and sectors
  - All US en route airspace is modeled
- Trajectories can be defined for objects
  - Defines 4D position of objects in simulation
  - Position used to determine line of sight, propagation delay, path loss, and interference for wireless channels
- Model trajectories can be imported from several sources
  - ASR-9 recordings
  - Extracted flight tracks
  - ACES/AwCNS tracks
- Trajectories can be combined with airspace data
  - Can determine the center/sector of an object at any time
  - Can determine boundary crossing times for objects
  - Can be used to trigger events, such as message generation



OPNET

OPNET Application Model

- Generic model capable of producing traffic to simulate multiple services
  - Messages can be generated following a statistical distribution, or,
  - When combined with the airspace model, messages can be triggered on events, such as crossing a sector boundary or transitioning domains
- Messages can represent data or voice traffic
- Models currently exist for COCR Phase I and II for enroute, terminal, and surface domains (statistical distribution)
  - Includes both ATS and AOC traffic

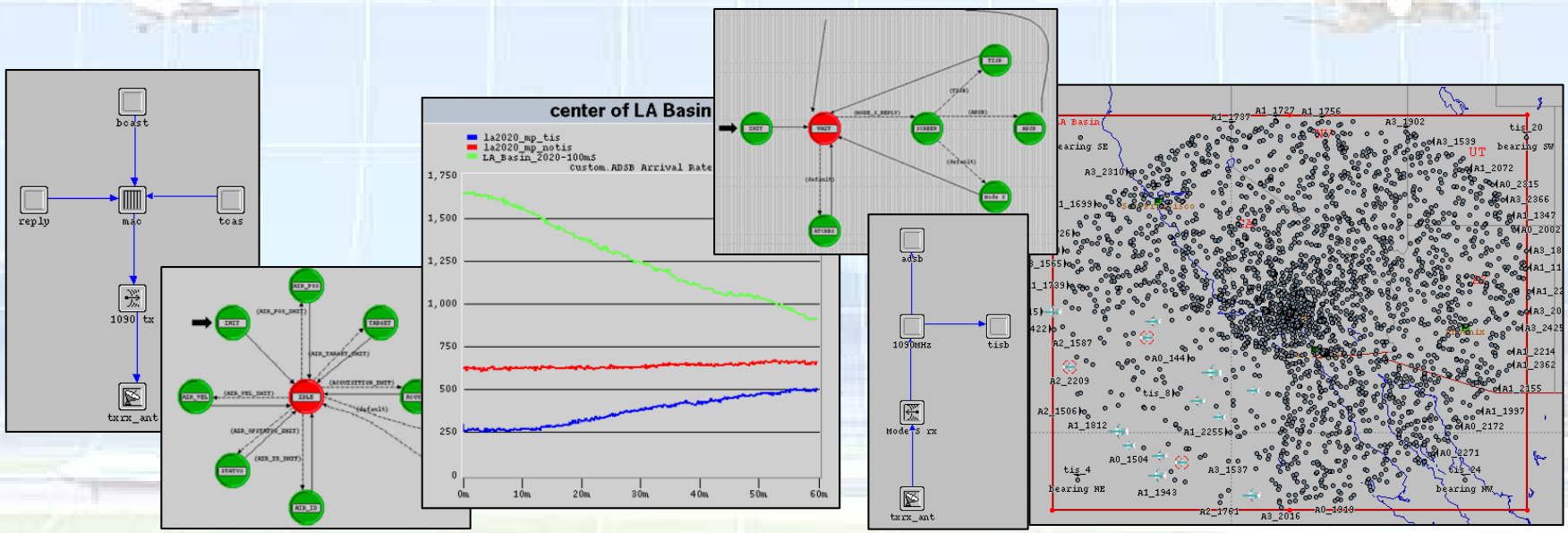



```
Service: High_UP Datalink
    Transaction: ACL_UP Uc 12
    Timing: Domain C 1.0 exponential(270)
    Message: ACL_UP poisson(112) U None

    Transaction: ACM_UP Uc 12
    Timing: Domain C 1.0 exponential(337.5)
    Message: ACM_UP poisson(240) U None

    Transaction: AMC_UP Uc 12
    Timing: Domain C 1.0 exponential(1417500)
    Message: AMC_UP poisson(96) U None

    Transaction: C&P_UP Uc 12
    Timing: Domain C 1.0 exponential(1350)
    Message: C&P_UP poisson(112) U None

    Transaction: D-ALERT_UP Uc 12
    Timing: Domain C 1.0 exponential(7988.9037037037)
    Message: D-ALERT_UP poisson(88) U None

    Transaction: DLL_UP Uc 12
    Timing: Domain C 1.0 exponential(18000)
    Message: DLL_UP poisson(3312) U None

    Transaction: D-RVR_UP Uc 12
    Timing: Domain C 1.0 exponential(9000.00000000001)
    Message: D-RVR_UP poisson(312) U None
```

OPNET

OPNET ADS-B Model

- ADS-B models designed for LA Basin 2020 scenario
  - Designed to accommodate over 1400 aircraft
    - > Ground systems not explicitly modeled and processing is limited for efficiency
  - ADS-B over UAT
    - > Models transmission of basic ADS-B message in pseudo-random UAT time slot
  - ADS-B over Mode S
    - > Models transmission of ID, position, velocity, and operational status ADS-B messages over Mode S



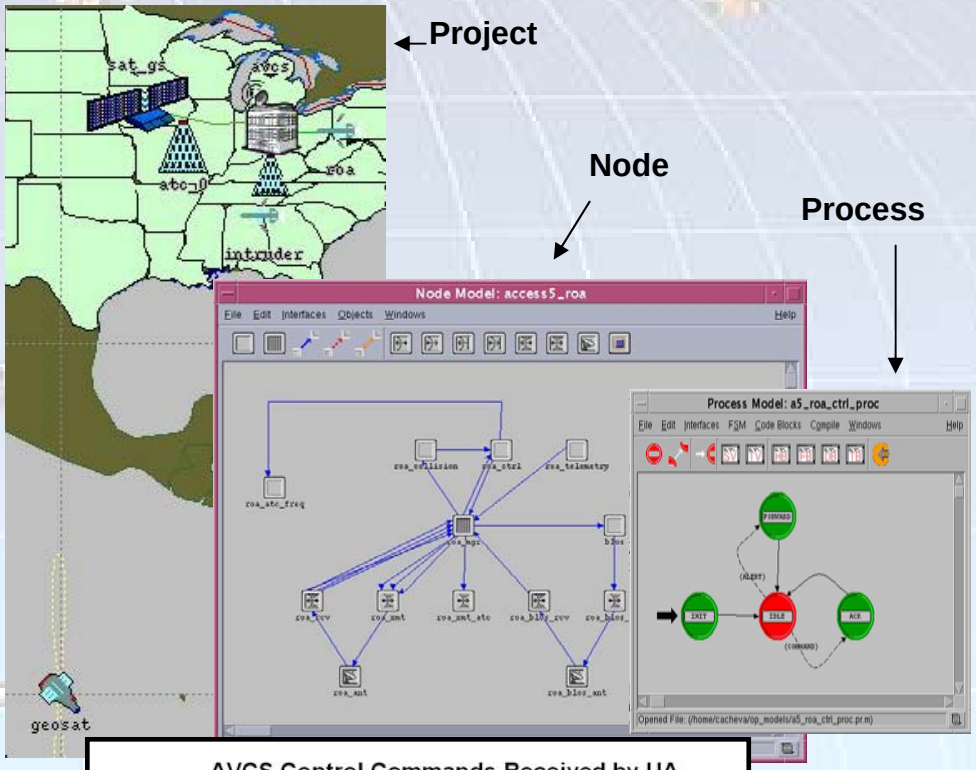
OPNET

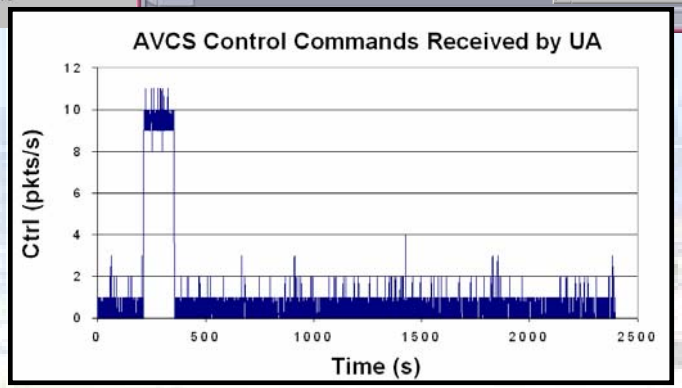
Access5 Unmanned Aircraft Simulations

Acess5 UAV/UAS Communications System Model

- Nodes: UAV, AVCS, ATC, Satellite, Satellite Ground Stations, Intruder Aircraft
- UAV communicates directly with ATC and Intruder
- Line of Sight (LOS): UAV communicates directly with AVCS
- Beyond LOS: UAV communicates w/ AVCS via satellite & ground station
- Data packet types: Voice, Telemetry, Control & Intruder alerts
- Statistics monitored: Throughput, End-to-end delay & Bandwidth utilization.

Completed first phase of development and simulation testing.



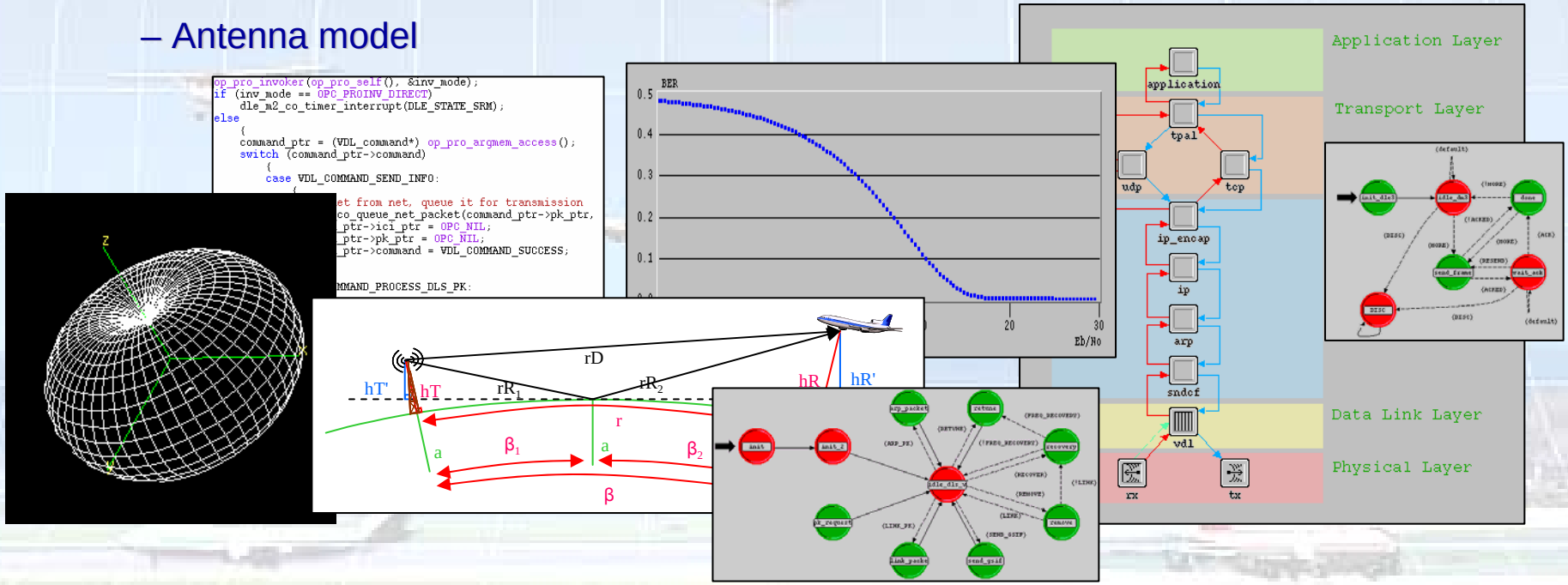


Statistic

OPNET

OPNET VDL Model

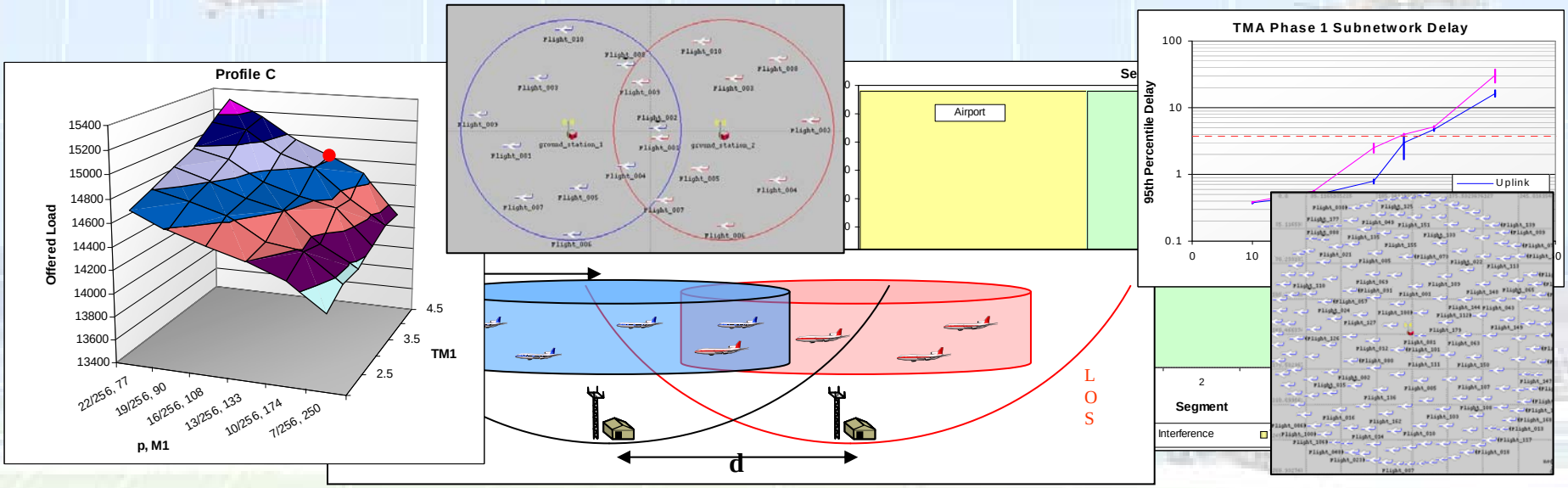
- VDL model is capable of simulating VDL Modes 2, 3, and 4
  - Mode 4 model does not include surveillance capability
- Includes:
  - Node models for aircraft and ground stations
  - Detailed process models for VDL MAC, DLS, and VME sublayers
  - Detailed pipeline model for 2-ray propagation path loss and received power
  - Modulation curves for D8PSK and GFSK
  - Antenna model



OPNET

VDL Mode 2 Frequency Planning Study

- A VDL subnetwork was to modeled to:
  - Determine capacity of VDL Mode 2 subnetworks for COCR traffic profiles
    - > Examined number of aircraft vs. delay, compared this to delay requirements
  - Examine VDL Mode 2 parameter optimizations
  - Evaluate VDL Mode 3 in same scenario using 3T and 1V3D configurations
    - > Required adding the 1V3D configuration to the model
    - > Included addition of a new optimized downlink random access algorithm
  - Examine hidden transmitter effects from ground stations using same frequency
  - Investigate co-site interference issues from aircraft voice transmissions
- In total, over 4,000 simulations were performed for this study



- Overview of NASA GRC Modeling, Simulation and Analysis Capabilities
  - ACES with CNS
  - OPNET
  - Other
  - Approach
- Some Simulation Examples
- Summary of Simulation Tools and CNS Models

Other Simulation and Analysis

Future Aeronautical Subnetworks Traffic Evaluator (FASTE) for CNS Systems - Modeling and Analysis Tool

Industry

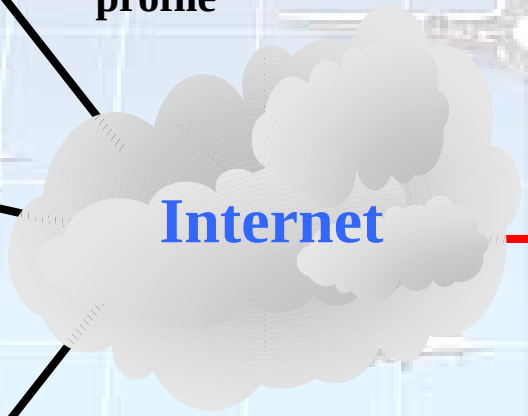
Government

IE / Netscape

Universities

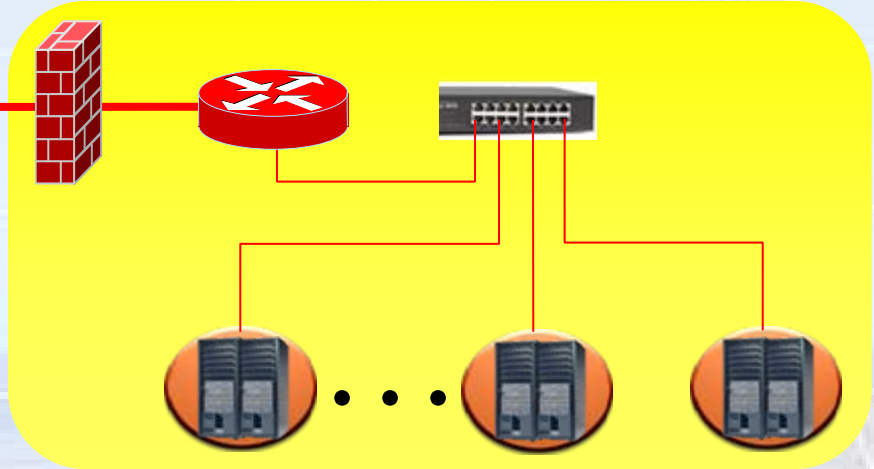
Steps

- **Define message set**
- **Media selection**
- **Communications Profile**
- **Communications load profile**



Capabilities

- **User Management**
- **Load/ Frequency Calculation**
- **Communication Model**
- **Navigation Model**
- **Surveillance Model**



Performance models
C: VHF Voice, ACARS and VDL Mode 2
N: VOR/DME, GPS
S: Secondary Radar, ADS-B (UAT)

Other Simulation and Analysis

FASTE-CNS Example: Modeling ATC Message Exchange

23. Approach, UA917 is with you out of one three thousand descending to one zero thousand, ten thousand, heading three three zero.

26. UA917, roger, right to three six zero and maintain four thousand

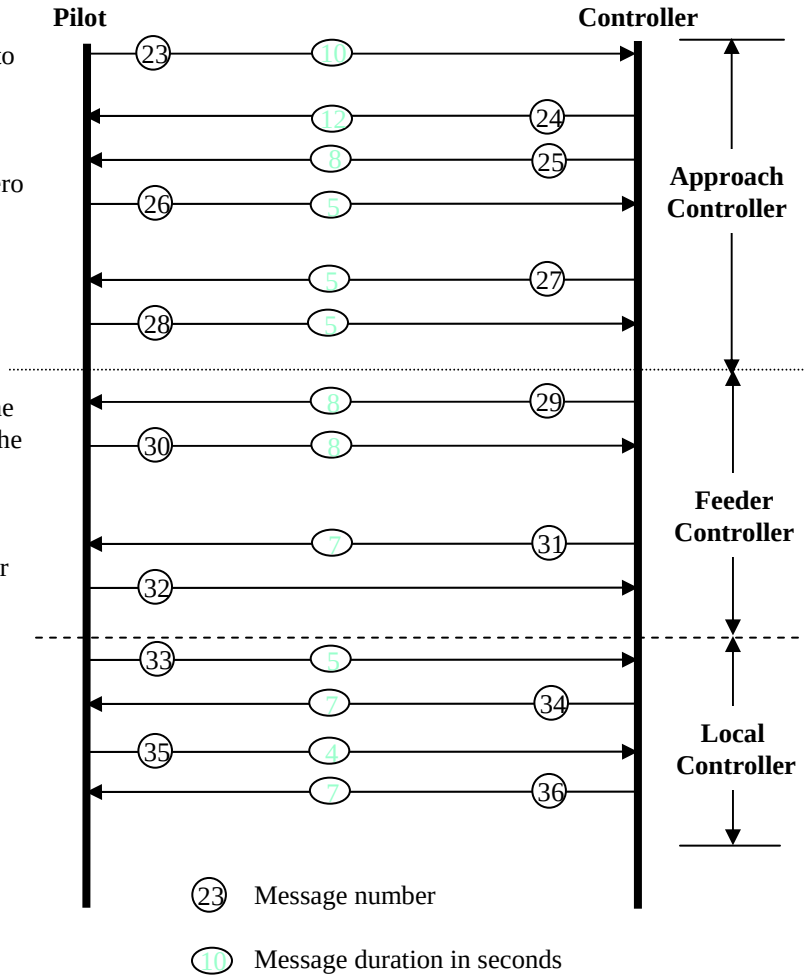
28. UA917, turn left heading two six zero, descend and maintain three thousand.

30. UA917, roger, left heading two one zero, three thousand until joining the localizer, and cleared for the ILS runway one niner right approach.

32. UA917, roger, tower one one niner point three and report the marker inbound.

33. Tower, UA917 is with you on the approach marker inbound.

35. UA917, roger, cleared to land runway one niner right.



24. Roger, UA917, Approach radar contact continue descent to four thousand heading three three zero vectors for an ILS runway one niner right approach.

25.UA917, Approach, turn right heading 360 three six zero and maintain four thousand

27. UA917, turn left heading two six zero, descend and maintain three thousand.

29. UA917, turn left heading two one zero, cleared ILS runway one niner right approach, maintain three thousand until joining the localizer runway one niner right.

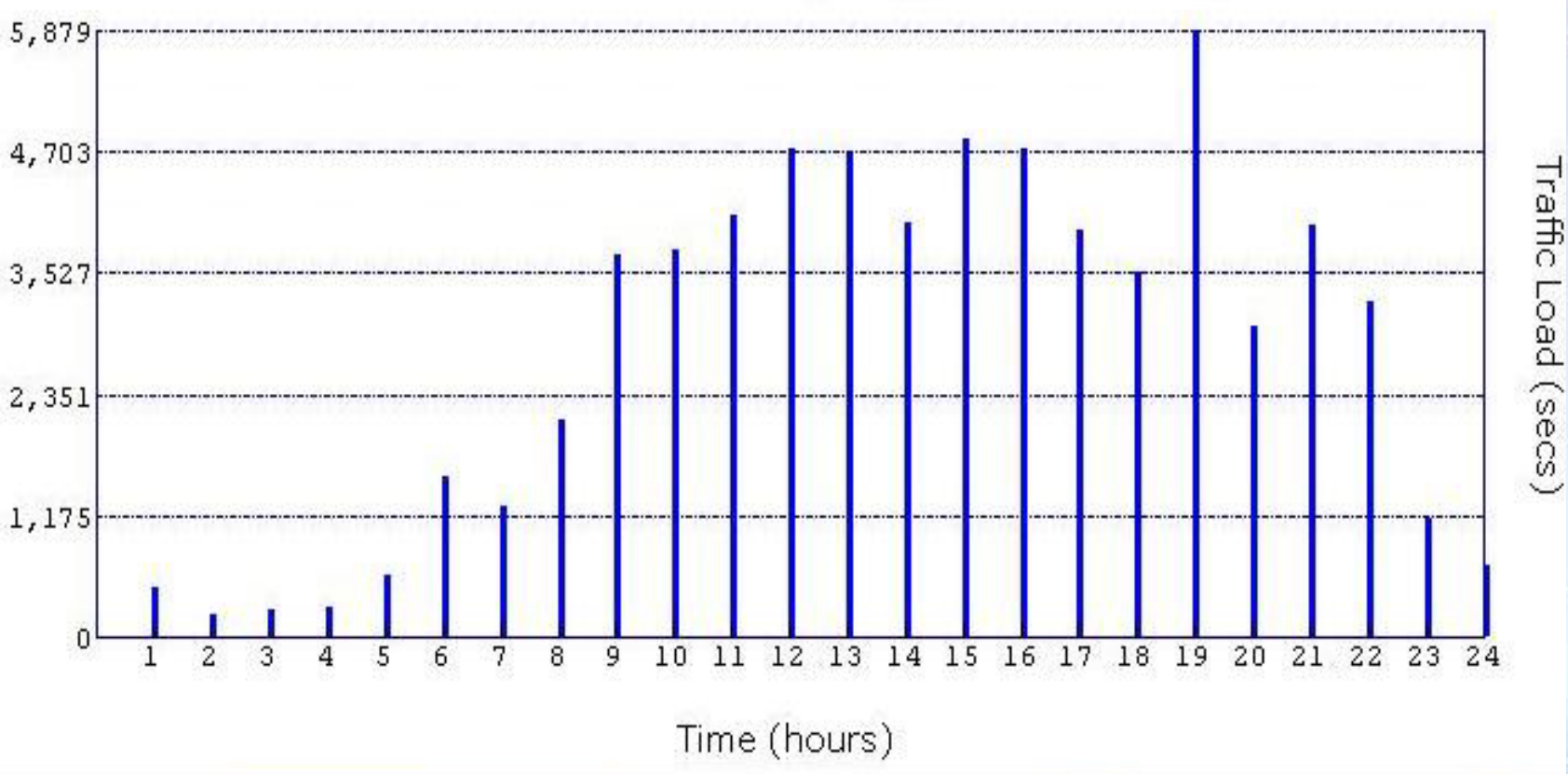
31. UA917, roger, contact Tower on one one niner point three and report the marker inbound.

34. UA917, Tower, roger, cleared to land runway one niner right, wind one seven zero at one five knots.

36. UA917, Tower, left turn at the next intersection, contact Ground Control point niner.

Other Simulation and Analysis

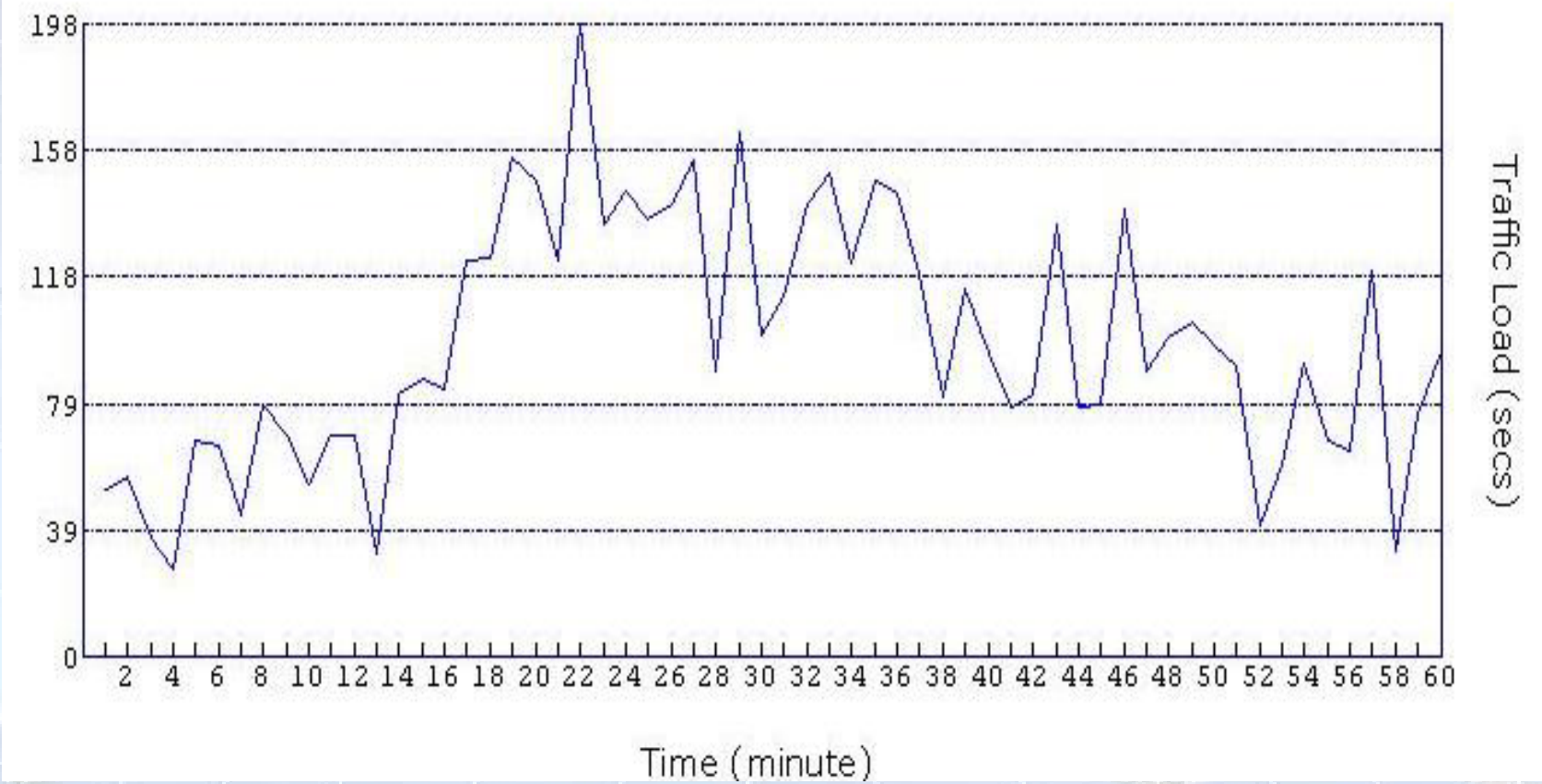
FASTE-CNS Example: MIA ATC Traffic Load Over 24 Hours



Total Number of Messages	***–***	***10,339***
Total Communications load	***–***	***66,758 seconds***
Average Communications load	***–***	***46.36 seconds/minute***

Other Simulation and Analysis

FASTE-CNS Example: MIA ATC Peak Hour Traffic Load



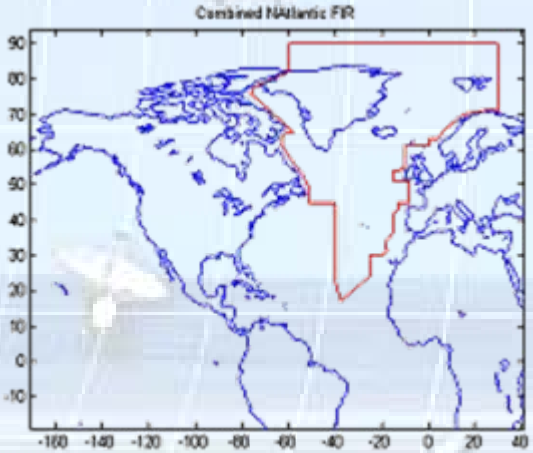
Total Number of Messages	***–***	***894***
Total Communications load	***–***	***5,879 seconds***
Average Communications load	***–***	***97.98 seconds/minute***

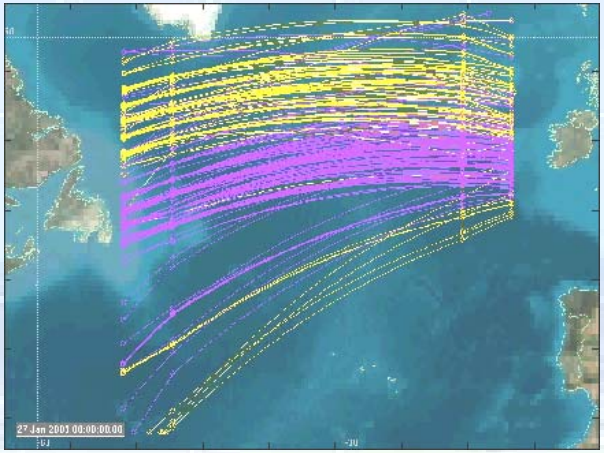
Other Simulation and Analysis

MatLab-based Simulation and Analysis Example: Enhanced Oceanic Situational Awareness for the North Atlantic Corridor

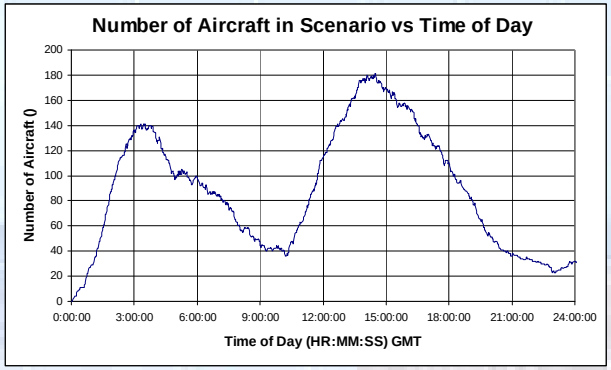
In this simulation, application of AMSS satcom to oceanic ADS-B was studied

- What satcom capabilities are required to provide surveillance sufficient to enable safe reduction of separation in oceanic environment?
- Reduction from 60 nm to 15 nm separation would increase geometrical corridor capacity by a factor of 15
- Can a LEO (Iridium-like) system provide adequate messaging capacity?





FAA flight data from July 18, 2001



West Bound Flights in Gold East Bound Flights in Purple

Other Simulation and Analysis

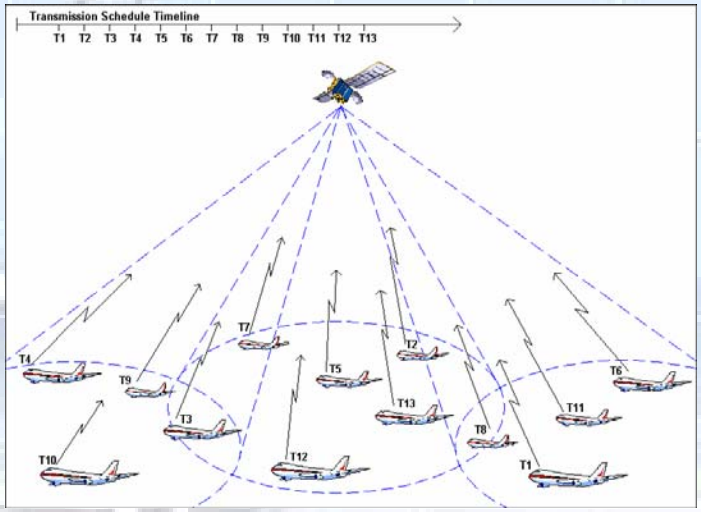
MatLab-based Simulation and Analysis Example: Enhanced Oceanic Situational Awareness for the North Atlantic Corridor

Parameters:

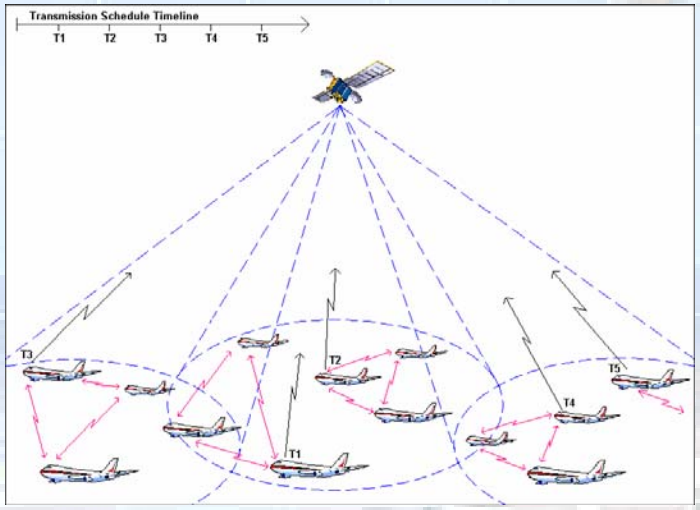
Required Navigation Performance (RNP); Message latency (aircraft to ATC; ATC to aircraft); pilot/aircraft response delay; average aircraft speed; speed variance between aircraft

Transmission Methods

- Method 1 – Single Aircraft Transmission at a Time
  - Case 1 – Own Data Transmission
  - Case 2 – Vicinity Data Transmission
- Method 2 – Maximum Aircraft Transmission at a Time
  - Case 1 – Own Data Transmission
  - Case 2 – Vicinity Data Transmission



Case 1



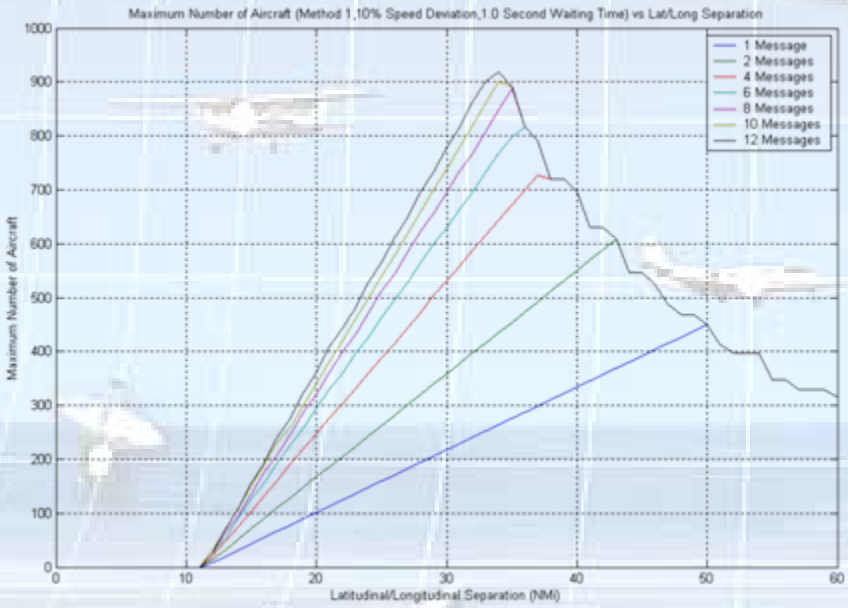
Case 2

Other Simulation and Analysis

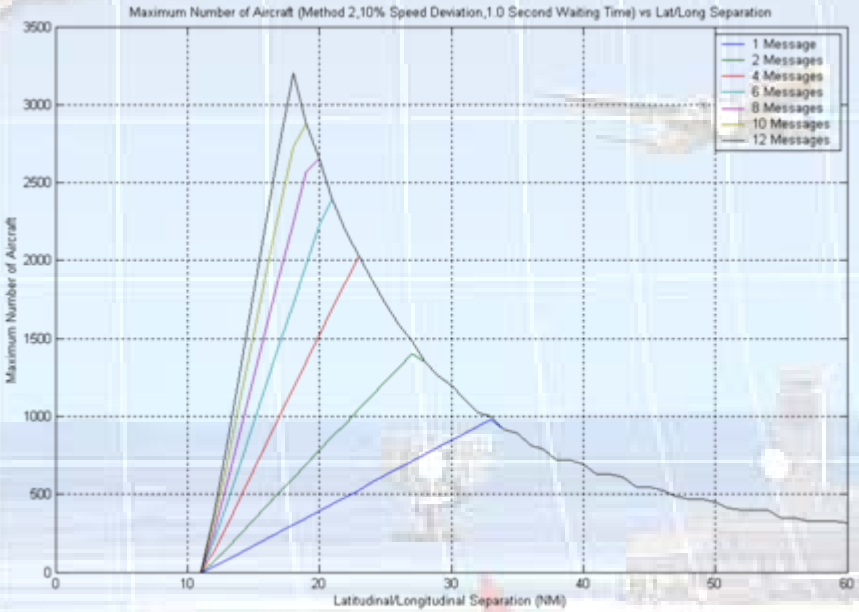
MatLab-based Simulation and Analysis Example: Enhanced Oceanic Situational Awareness for the North Atlantic Corridor

Results:

In this analysis, the satcom system can support up to an 888% increase in traffic via transmission method 2.



Method 1



Method 2

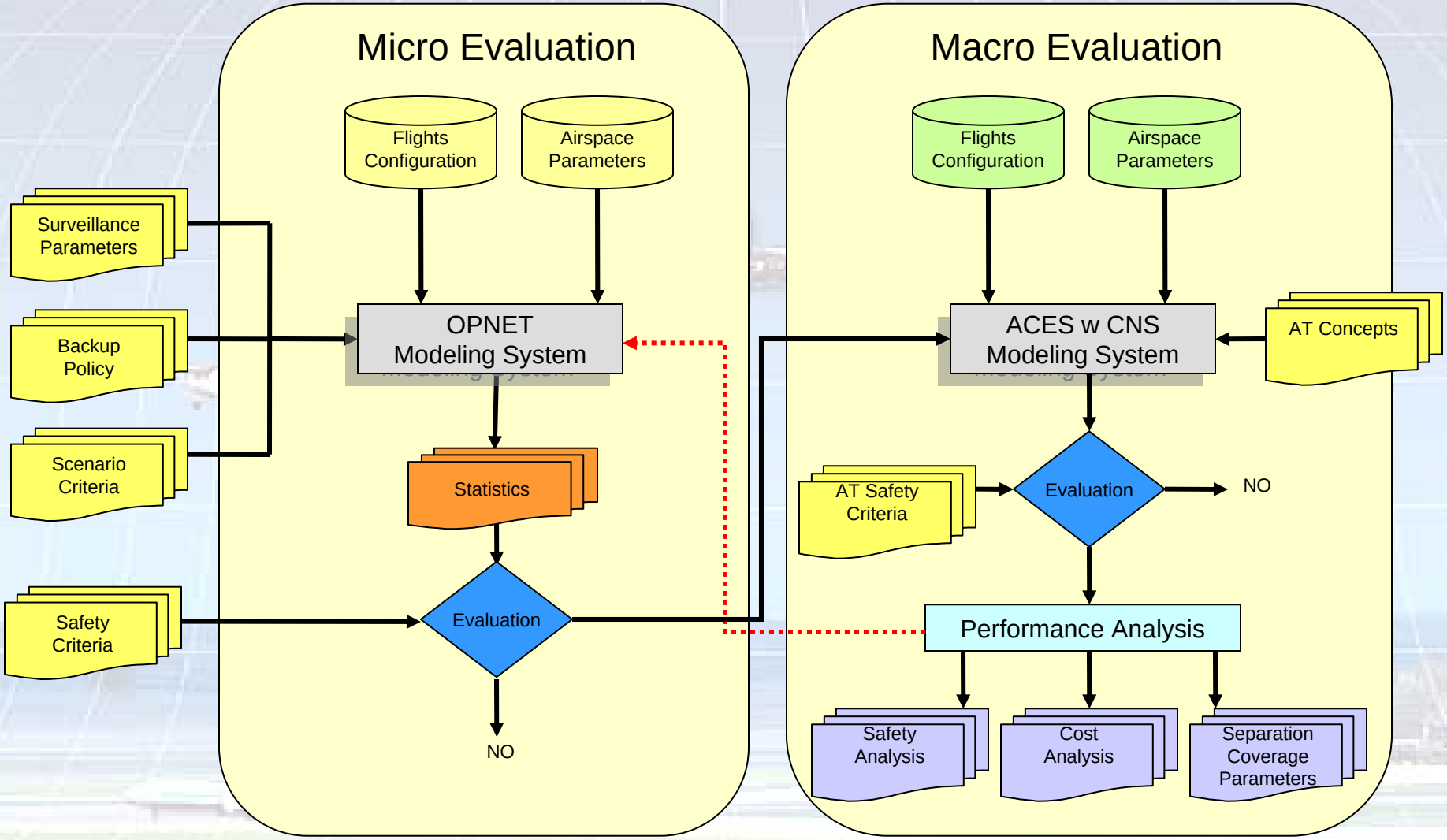
- Overview of NASA GRC Modeling, Simulation and Analysis Capabilities
  - ACES with CNS
  - OPNET
  - Other
  - Approach
- Some Simulation Examples
- Summary of Simulation Tools and CNS Models

Approach to Simulation Development

- Mission Definition
  - Input parameters; desired outputs
- Scenario Development
  - Relevant airspace concepts of use; rules; procedures
  - Simulation scenario definition
- Simulation Requirements
  - Fixed and variable parameters; AT control; airspace; technologies; constraints; metrics; etc
  - Model development and enhancement requirements
  - Simulation enhancements
  - Analysis requirements
- Simulation Design
  - Define alternative approaches
  - Selection of best balanced solution
- Modeling & Simulation Execution
  - Develop and Test Models
  - Simulation Stages – Build, validate
- Analyze and Report Results
  - Develop, enhance, apply analysis tools
  - Findings, conclusions, recommendations

Approach to Simulation Development

Simulation Flow Diagram Example



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Modeling/Simulation/Analysis Example 1

Simulation and Analyses of Safe Separation Minima in ADS-B Airspace

Analysis of Safe Separation Minima in ADS-B Airspace

Objective: Analyze safe minimum separation of aircraft in airspace where ADS-B is the primary surveillance system.

Scenarios:

- US continental airspace where ADS-B is operational.
  - To what minimum distance can en-route separation be safely reduced?
  - To what minimum distance can terminal separation be safely reduced?
  - What are the minima in a mixed equipage environment?
  - Is there a dependence on traffic volume?
- Study subsets of US continental airspace:
  - Terminal Airspace
  - Transition from En-route to Terminal Airspace – merging & spacing

Other Options:

- Analyze off-nominal system operation – GPS outage, ADS-B GS failure, airborne avionics failure, etc
- Variation in geographical location of surveillance facilities

Analysis of Safe Separation Minima in ADS-B Airspace

Simulation Parameters:

- Airspace characteristics
  - Operating domain, aircraft density, geographic location, weather
- Aircraft parameters
  - Full ADS-B equipage, partial equipage (i.e. 75%, 50%, etc)
- Separation parameters
  - Aircraft controlled to maintain minimum separation of 3 nm, 2, nm, 1 nm…
- ADS-B performance; SSR performance
- ATM rules and procedures (e.g. merging and spacing, etc.)

Simulation Outputs:

- Flight path parameters; surveillance reports; communications/messages; message delay; aircraft throughput, arr/dep delay; simulation visualization

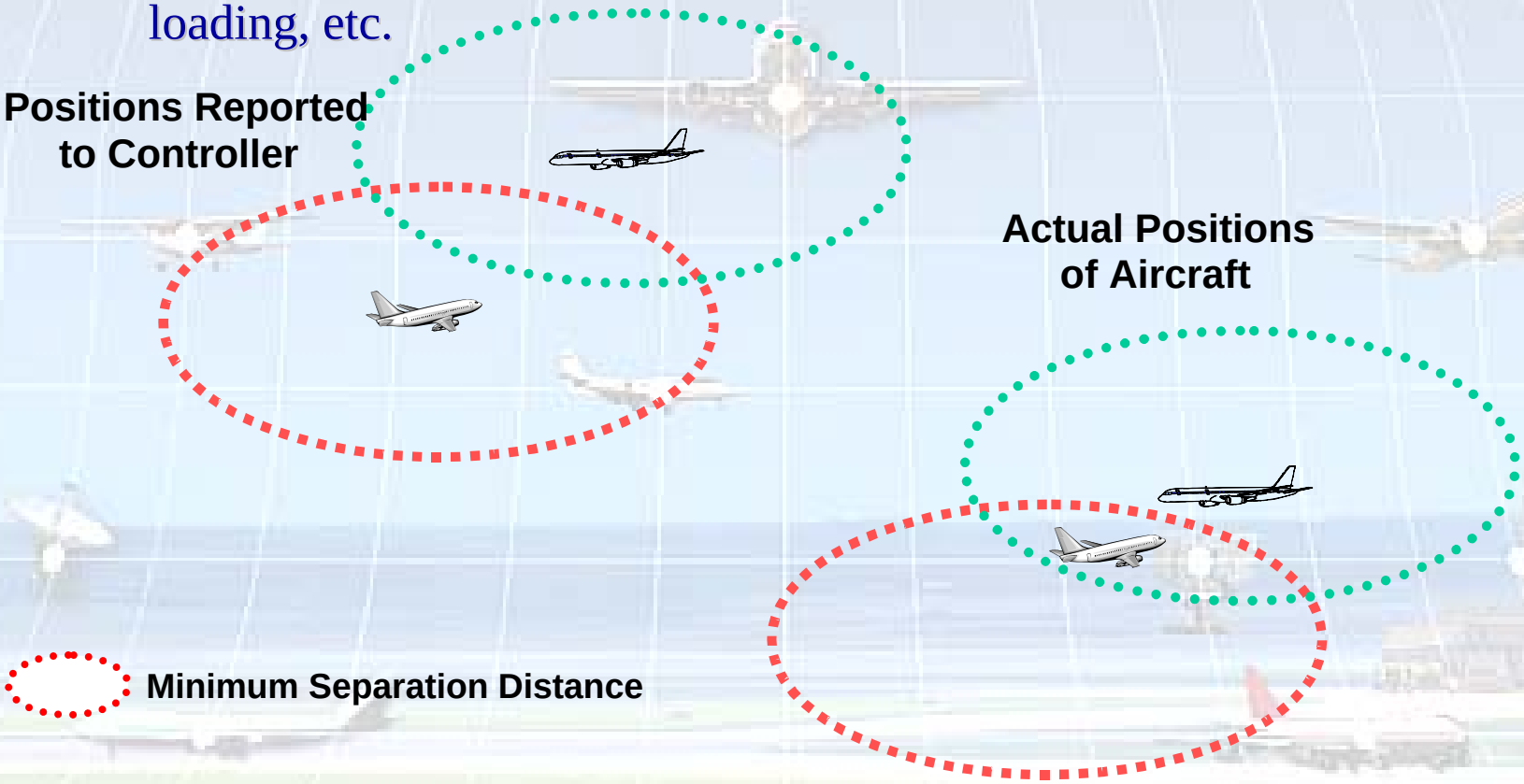
Analysis:

- Position report (i.e. surveillance) errors; loss of separation minima incidents; communications traffic loading; system throughput (vs. separation minima; nominal and off-nominal operations; mixed equipage, varying rules and procedures; etc.)

Analysis of Safe Separation Minima in ADS-B Airspace

Separation Analysis

- Using AwCNS, CONUS operations are simulated for 24 hours applying various aircraft spacing rules, equipage %, etc.
- Resulting flight path parameters and other outputs are analyzed for separation violations, message errors/delays, communications loading, etc.



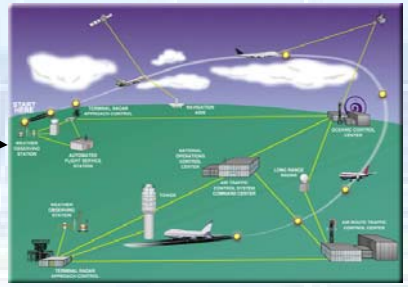
Analysis of Safe Separation Minima in ADS-B Airspace

Simulation Overview

ACES with CNS

- En Route, Terminal or Both
- Busy Traffic Day (20,000+ Aircraft in 24 hrs)
- Set Minimum Separation Distance for ATC Agent

Aircraft Locations (per unit time)



STK Dynamic Visualization

FASTE-CNS

- Import ACES Data
- Calculate Separation Distance Between Aircraft
- Compare Separation Distance with Minimum
- Record Violations of Minimum Separation Distance

Statistics on Separation Distance Violations

Modeling/Simulation/Analysis Example 2

TRACON/Airport Airspace Approach Analysis

Analysis of TRACON/Airport Airspace Approaches

Objective: Provide Surveillance Systems performance comparisons for A/C Approaches in TRACON/Airport airspace. Analyze current operations, new concepts, 4D trajectories and varied airport configurations.

Scenario:

- Focus on Aircraft activity from TRACON fixes to within the TRACON/Airport airspace.
- Use Flight Data Sets that demonstrate aircraft merging, maneuvers and close aircraft proximity
- Apply varied airport capacity rules in ACES.
- Apply varied separation/spacing rules in ACES.
- Use varied airports and airport configurations.

Analysis of TRACON/Airport Airspace Approaches

Simulation Parameters:

- Airspace Characteristics: Operating domain, aircraft density, geographic location, weather
- Surveillance Capability: Full ADS-B equipage, partial equipage (i.e. 75%, 50%, etc), SSR, MLAT
- Varied mix of aircraft type
- Aircraft Maneuvers within the TRACON

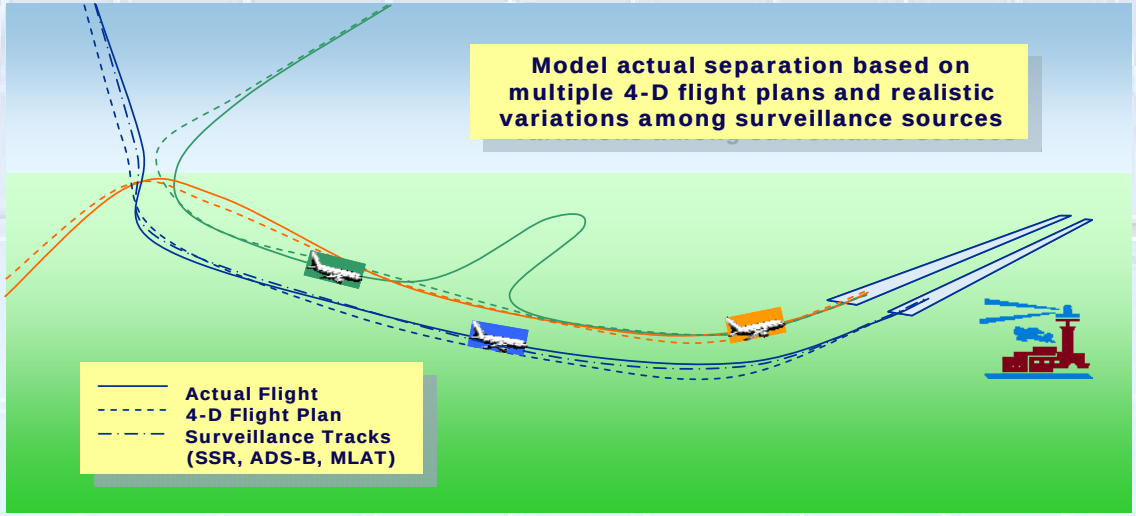
Simulation Outputs:

- Aircraft proximity/timing statistics relevant to ATC / Aircraft Ops
- Surveillance systems performance data
- Communications/messaging activity data
- Aircraft throughput data
- Simulation visualizations

Analysis of TRACON/Airport Airspace Approaches

Analysis

- Assess variations in surveillance performance monitoring in separation assurance applications
- Perform Analysis using Large Scale simulations (AwCNS) and Enhanced detailed (OPNET) models/simlationsresults for SSR, ADS-B and MLAT.



Reporting

- Report on Position (i.e. surveillance) errors, Loss of separation minima incidents; Communications traffic loading; System throughput
- Analysis for separation minima; nominal and off-nominal operations; mixed equipage, varying rules and procedures; etc.)

Modeling/Simulation/Analysis
Example 3

Surveillance Performance and Optimization Simulation and Analysis

Surveillance Infrastructure Reduction

Surveillance Performance and Optimization Simulation and Analysis

Objective: Analyze potential to safely reduce NAS Surveillance Infrastructure cost in a future ADS-B environment

- Evaluate coverage and separation standards impact
- Assess cost reduction

Scenarios:

- En-Route Airspace – ADS primary, ARSR backup
  - Reduction to beacon only at selected sites.
  - Reduction of LRR facilities utilizing MLAT backing
  - Military Surveillance

- Terminal Area Airspace - ADS-B primary
  - Use ARSR for backup
    - Altitude coverage, Separation minima
  - MLAT/LRR backup operation

Surveillance Performance and Optimization Simulation and Analysis

Simulation Parameters:

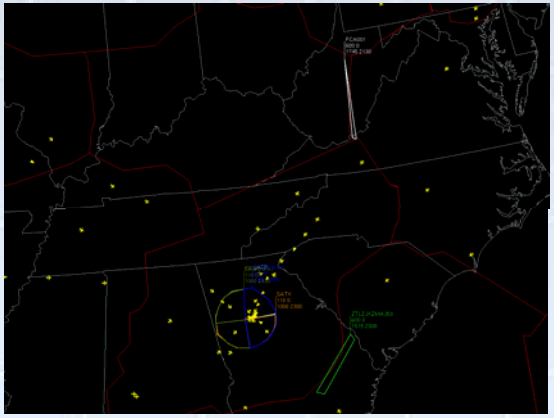
- ARSR/ASR locations
- ARSR/ASR technology capabilities (failure assessment, backup capabilities-M/S, etc)
- Radar, Automation capabilities
- ADS-B capabilities

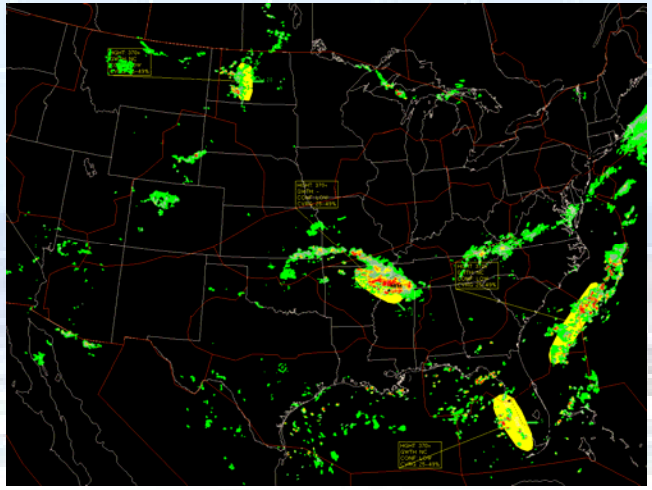
Simulation Outputs:

- Flight parameters; Surveillance reports vs. location; Aircraft throughput, arr/dep delay

Analysis:

- Surveillance system coverage vs. safety
- Surveillance system coverage vs. cost
  - Operational cost: Telco, Personnel, Leasing, Parts, Training, Logistics
  - Other: Spectrum
- NAS Performance





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Summary of Simulation Tools and CNS Models

ACES - Developed by NASA for Simulating the physical movement of aircraft in the NAS

- Simulates NAS entities (ATCSCC, ARTCC, TRACON ATC, Airport ATC, Aircraft).
- Simulates NAS ATM operations (TFM, CDR, Separation rules, Sector restrictions, etc).
- Enables testing of alternative roles and forecasting methods for ATM Command and Control.
- Models the dynamic interaction between NAS Agents.
- Used for analyzing Airspace Concepts; developing decision support and automation tools
- Fast-time, nationwide simulation can include one to thousands of flights.
- Full flight schedule with flight plans, 4-D gridded winds, gate-to-gate operations
- High-fidelity 4-D aircraft trajectory models; aircraft physical models; pilot-based control

AwCNS – Developed at GRC to add CNS functions into ACES Simulation Environment

- CNS enhancements added during development for realistic Flight / ATC / ATM / CNS interactions.
- Models include: VHF/Voice, CPDLC over VDL2, GPS and VOR/DME Nav, SSR and ADS-B Surv
- Generates detailed CNS system performance data in NAS-wide, air traffic environment.
- Provides flexibility for integration of new models (process already established).
- Fully configurable for Aircraft/CNS System equipage and varying CNS system parameters.
- Takes full advantage of ACES functionality including NAS Entities and ATM/Flight Operations

Summary of Simulation Tools and CNS Models

OPNET / OPNET Modeler

- Discrete event simulation package
  - Processes
  - Protocols and Applications
  - Devices
  - Communications systems
- Includes hundreds of protocols and devices
- New protocols and devices can be created
- Modular design
- Supports fixed, mobile, and satellite nodes

Other Simulation and Modeling Tools

- FASTE-CNS
- Satellite Toolkit
  - Visualization Capabilities
- MatLab

NASA Glenn Partners in Simulation/Modeling/Analysis

- Cleveland State University
- Ohio University
- CNS Inc.
- IAI
- Mulkerin Associates
- Seagull Technologies
- ITT Inc.

All are available under existing contracts or cooperative agreements

Summary of Simulation Tools and CNS Models

CNS Systems Modeled in OPNET and AwCNS

- VHF Data link - Modes 2, 3, and 4
  - CPDLC and generic data packets
- VHF Voice
- Automatic Dependent Surveillance – Broadcast
  - Universal Access Transceiver
  - Mode S (extended squitter)
- Flight Information Service (FIS)
- Traffic Information Service (TIS)
- Communications Standards Identified in Future Communications Study
  - P-34
  - LDL (VDL-3 in L Band)
- SatCom Models
- GPS
  - WAAS and LAAS
- VOR/DME
- SSR

Internet Protocol and Wireless Standards models

- IPv4, IPv6 stack including Mobile IP
- 802.11 Wireless Networking Standards
- 802.16 (WiMAX) Wireless Networking Standards