Communications, Navigation and Surveillance Models in ACES

Test Results and Sample Concept Simulation Results

I-CNS Conference

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GRC Project Objectives and Teaming

Annual Project Objectives

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

Project Team

NASA GRC - Project Management / Test and Verification
Analex Corp. - System / Model Integration Engineering
Intelligent Automation Inc. - System Design / Software Development
CNS, Inc. - CNS Model Design / Model Integration
RSIS, Inc. – Software Configuration Management

Presentation Objectives

Overview of the ACES / CNS System Models and Modeling Enhancements

Present Test Results of CNS System Modeling completed to date

Present Test Results of CNS System Modeling Enhancements completed to date

Present results of a sample Concept to demonstrate capabilities

Baseline CNS Models Description

Voice Communication with VHF Radio Model

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

VOR/DME Navigation System Model

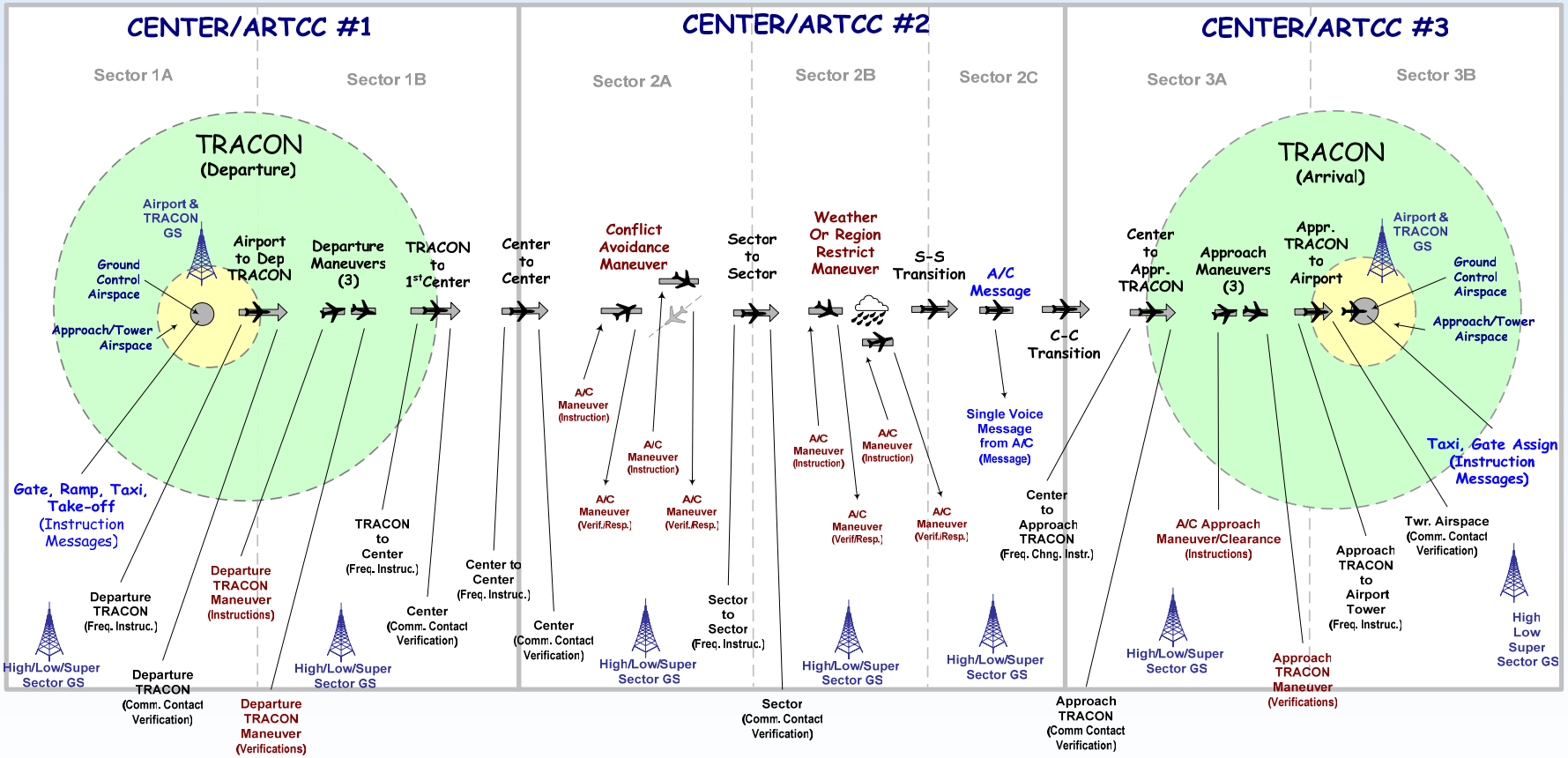
- Simulates On-board Navigation System (Statistical model)
- Uses ACES Flight Agent, ideal state data as reference, input data
- Provides non-ideal, reported position (Lat/Long) as would be viewed by the Pilot
- Uses a mapped network of Navaid Ground Stations (FAA Data)
- Uses calculated Slant Range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

Secondary Surveillance Radar (SSR) Surveillance System Model

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

Voice and CPDLC Communication Messages

SIMULATED COMMUNICATION MESSAGES – TYPICAL FLIGHT



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

Voice Communication – Simulation Results

IAD to SEA Single Flight

Departure Gate to Takeoff Message Sequence

FLIGHT INITIATED

Description	Scenario Seq #	sequence ID	activityId	simulation Time	Message Delay (ms)	agentId	transmit Direction	nas Facility ID
	1	1	FlightPilotActivity.Cybele_294	1116446400002		Flight2	AtoG	KIAD
		3	VoiceCommunicationActivity	1116446403005	3	CommunicationAgent.AIRPORT.KIAD	AtoG	KIAD
	2	1	AirportDepartureActivity	1116446403006		AirportAtc.KIAD	GtoA	KIAD
		6	VoiceCommunicationActivity	1116446428009	3	CommunicationAgent.AIRPORT.KIAD	GtoA	KIAD
			94	1116446428010		Flight2	AtoG	KIAD
			y	1116446453013	3	CommunicationAgent.AIRPORT.KIAD	AtoG	KIAD
			94			ght2	AtoG	KIAD
			y			ent.AIRPORT.KIAD	AtoG	KIAD
						Atc.KIAD	GtoA	KIAD
			y				oA	KIAD
	6	4	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		18	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
	7	5	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		21	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
Gate, Taxi, Takeoff Sequence	8	3	AirportDepartureActivity			Atc.KIAD	GtoA	KIAD
		24	VoiceCommunicationActivity			ent.AIRPORT.KIAD	GtoA	KIAD
	9	6	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		27	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
	10	7	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		30	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
	11	4	AirportDepartureActivity			Atc.KIAD	GtoA	KIAD
		33	VoiceCommunicationActivity			ent.AIRPORT.KIAD	GtoA	KIAD
	12	8	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		36	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
	13	9	FlightPilotActivity.Cybele_294			ght2	AtoG	KIAD
		39	VoiceCommunicationActivity			ent.AIRPORT.KIAD	AtoG	KIAD
	14	5	AirportDepartureActivity	1116447057004		AirportAtc.KIAD	GtoA	KIAD
		42	VoiceCommunicationActivity	1116447062007	3	CommunicationAgent.AIRPORT.KIAD	GtoA	KIAD
	15	10	FlightPilotActivity.Cybele_294	1116447062008		Flight2	AtoG	KIAD
		45	VoiceCommunicationActivity	1116447065011	3	CommunicationAgent.AIRPORT.KIAD	AtoG	KIAD
	16	6	AirportDepartureActivity	1116447114000		AirportAtc.KIAD	GtoA	KIAD
		48	VoiceCommunicationActivity	1116447117003	3	CommunicationAgent.AIRPORT.KIAD	GtoA	KIAD
	17	11	FlightPilotActivity.Cybele_294	1116447117004		Flight2	AtoG	KIAD
		51	VoiceCommunicationActivity	1116447120007	3	CommunicationAgent.AIRPORT.KIAD	AtoG	KIAD

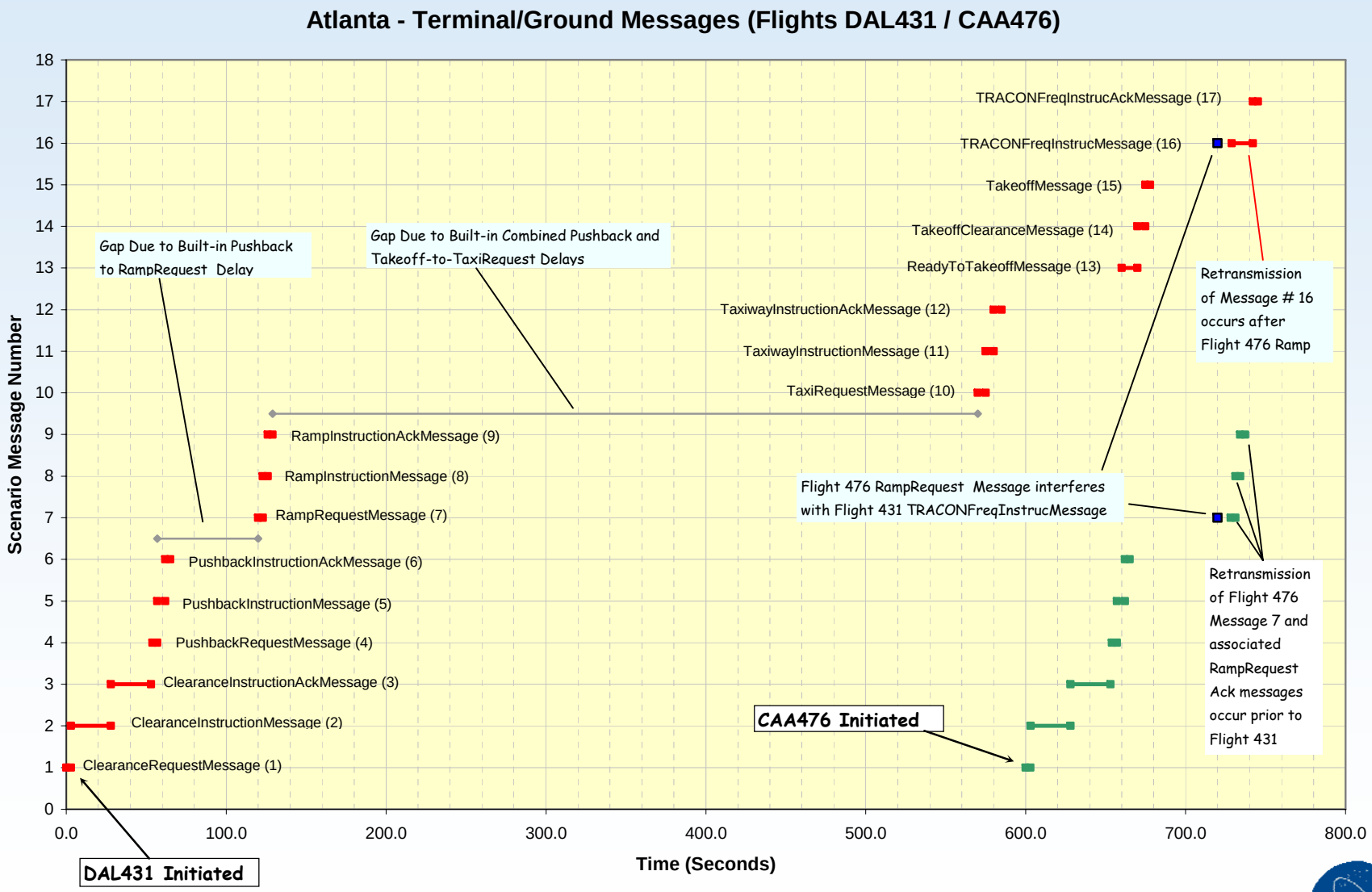
1	ClearanceRequestMessage
2	ClearanceInstructionMessage
3	ClearanceInstructionAckMessage
4	PushBackRequestMessage
5	PushBackInstructionMessage
6	PushBackInstructionAckMessage
7	RampRequestMessage
8	RampInstructionMessage
9	RampInstructionAckMessage
10	TaxiRequestMessage
11	TaxiwayInstructionMessage
12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

from voiceScenarioDescription.csv

Dep TRACON Freq Instr

Voice Communication – Simulation Results

122 Flight Simulation – Gate Depart to Takeoff Msg Sequence



Voice Communication - Simulation Results

IAD to SEA Single Flight

Center Transition and

Sector Transition

Freq Handoff Messages

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

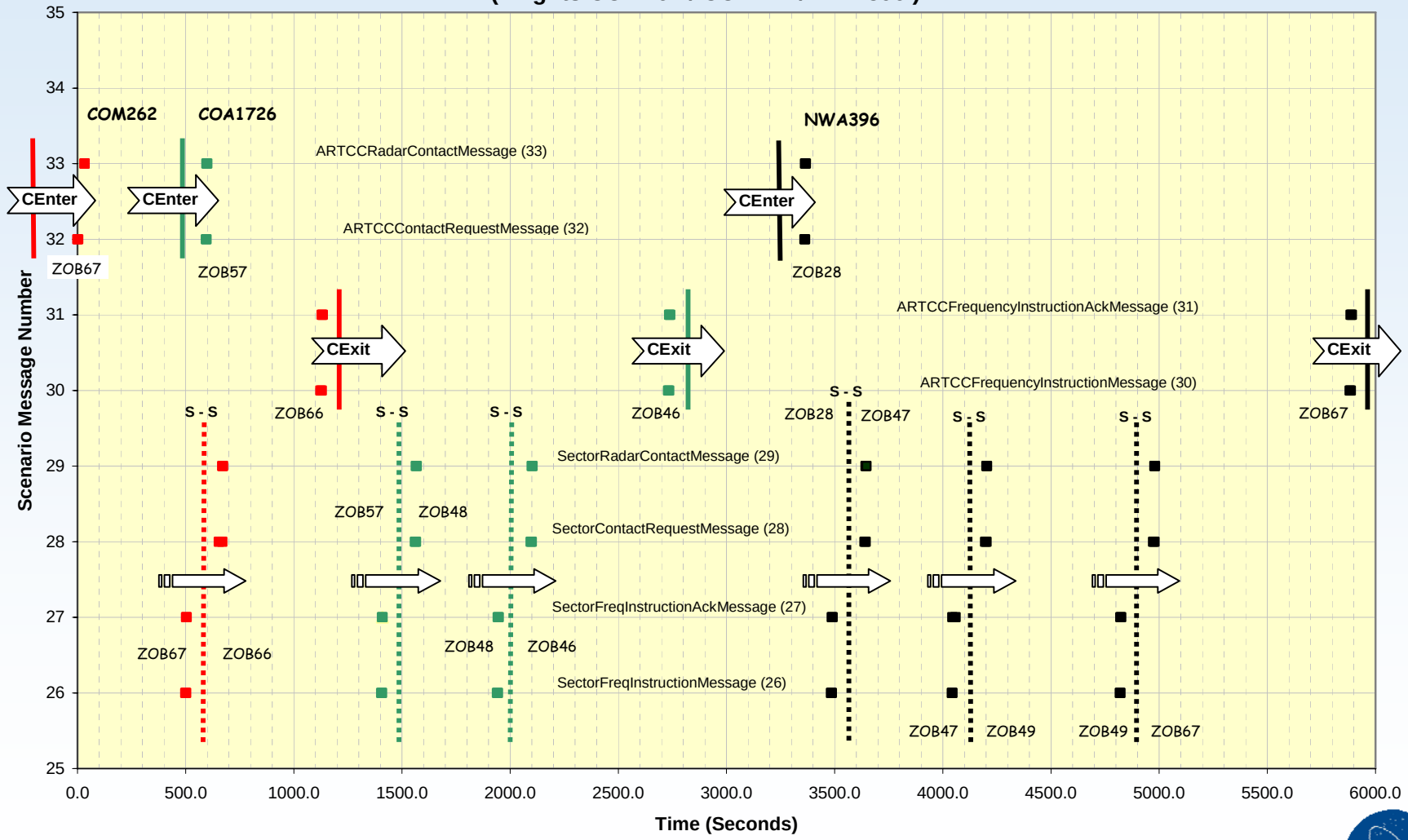
Enters 1st Center

Enters Next Sector

Voice Communication – Simulation Results

122 Flight Simulation – Center and Sector Frequency Handoff Msg Sequences

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



Navigation (VOR/DME) Characterization Test Results

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

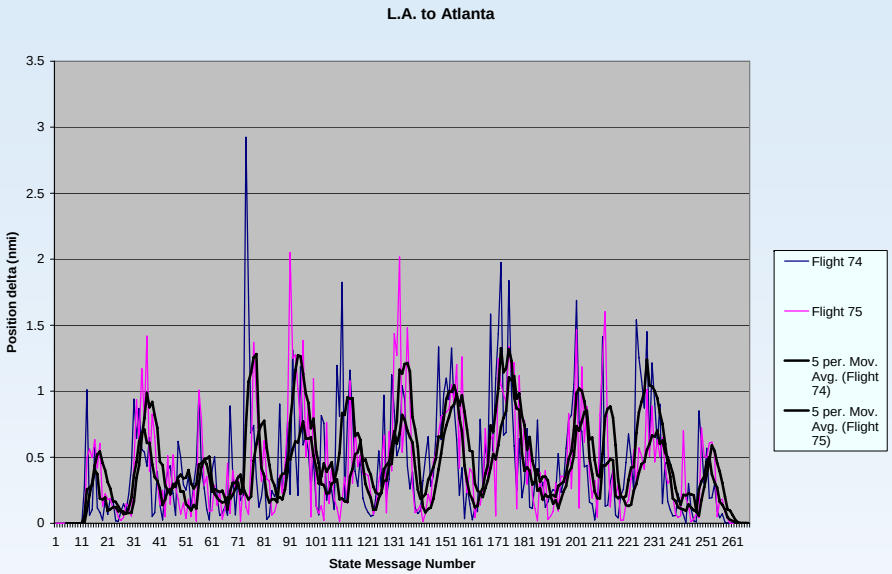
➢ Typical resulting plot showing difference between true and reported position (i.e. position delta) for each Flight Agent State message (1/min)

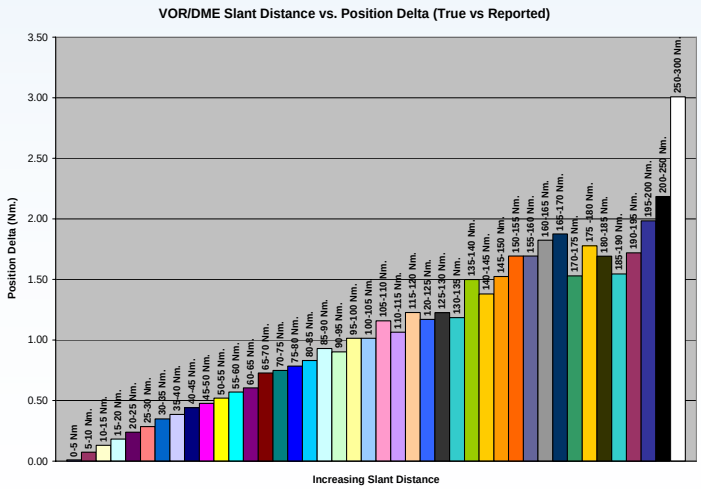
➢ Cyclical pattern in all plots due to Slant Range value effect on model accuracy

- 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



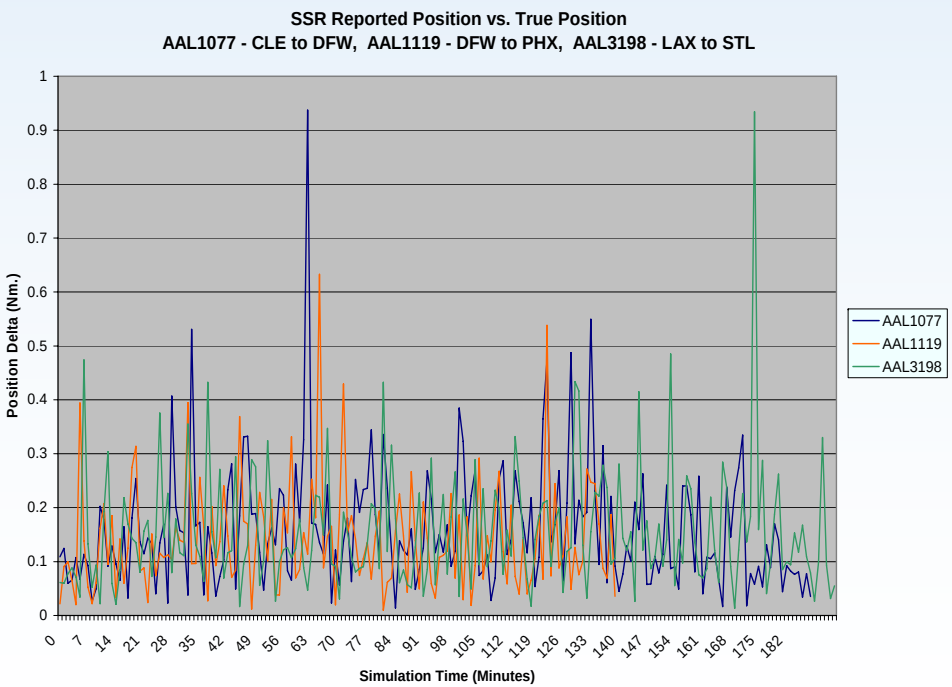


Surveillance (SSR) Characterization Test Results

- **Used 122 Flight Simulation for Testing**

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

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



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

Enhanced Capabilities Description

Voice Activated Maneuvers

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

Short Sector Transition Time (Freq Handoff Messages)

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

Enhanced Terminal Frequency Assignments

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

Navigation – Closed Loop Operation

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

Surveillance – Closed Loop Operation

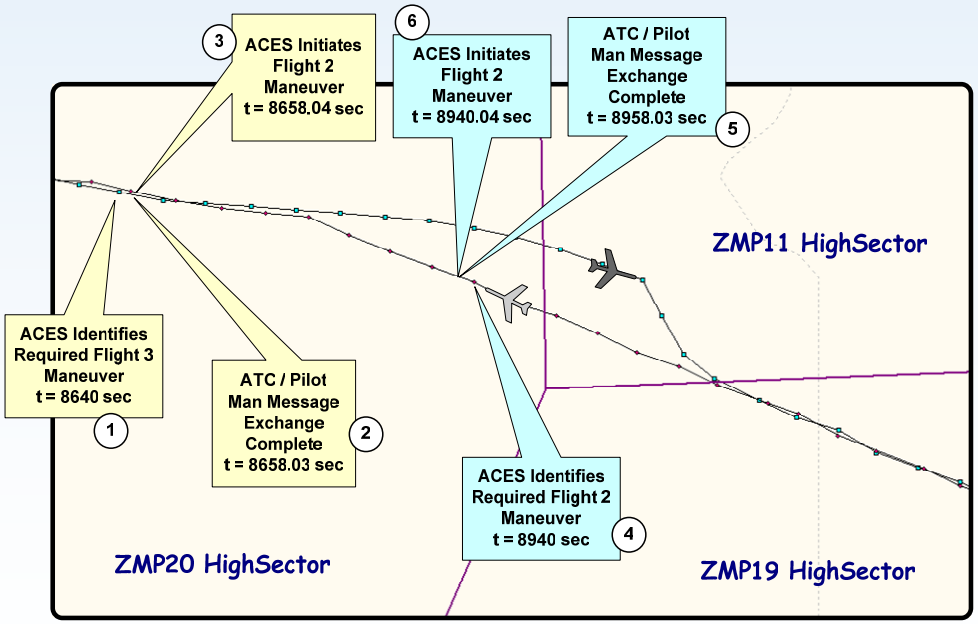
- Surveillance systems provide position information to Air Traffic Controllers
- Surveillance information is used real-time for ATC operations and decision making.
- CL allows accuracy of surveillance system models to be reflected into ATC operations and decision making.

Communication Activated Maneuvers Enhancement - Results

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

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

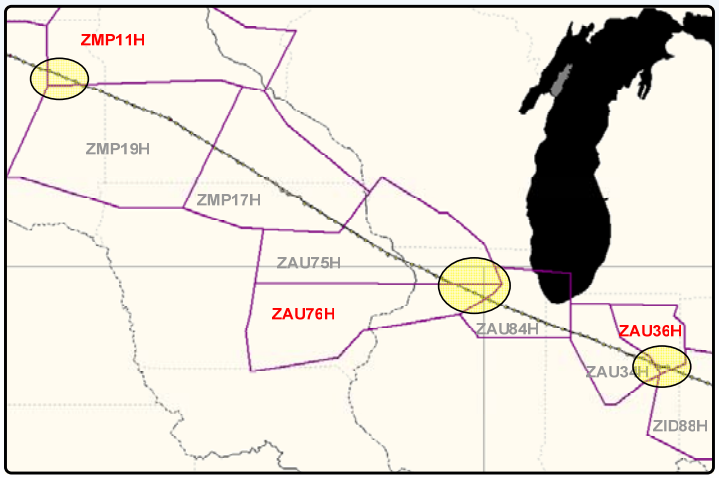
➢ ACES generated two maneuvers. Both were initiated following voice message transmissions.



Short Sector Transition Time Enhancement - Results

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

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



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

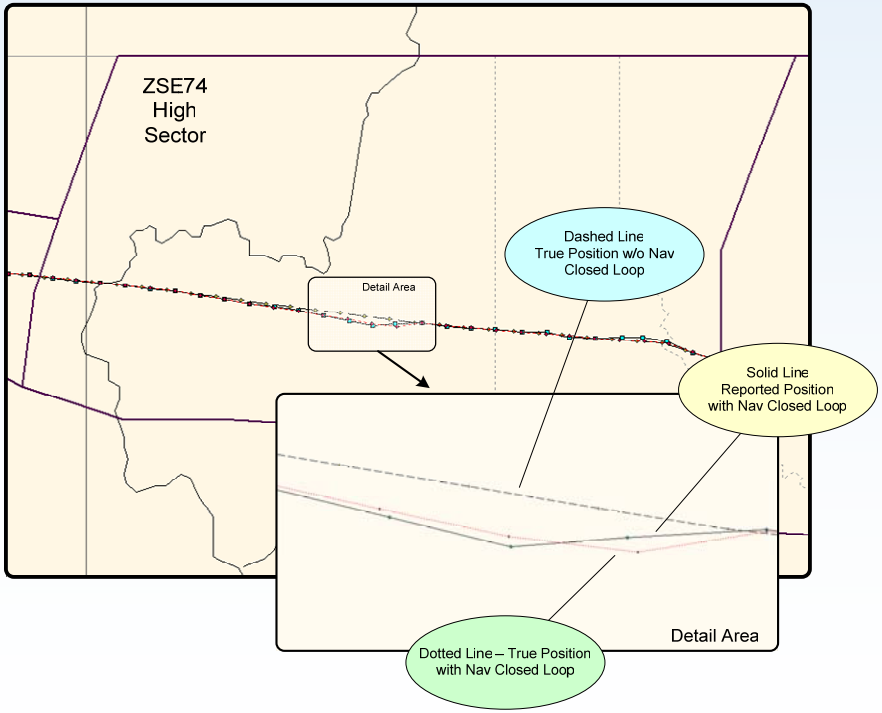
Navigation Closed Loop Enhancement - Results

- Simulated a single flight with VOR/DME enabled and with/without Closed Loop Navigation enabled to determine the effect on the anticipated variation in flight path.

➢ Several deviations from ACES flight path were observed. (shown in detail view below)
➢ Aircraft returned to planned waypoints – control loop seems functional

- From Simulation with 122 flight, FDS (testing to see if flight durations lengthened)

➢ Average flight durations increased by 6.2 minutes



New CNS Models Description (FY06)

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

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

GPS Navigation System Model

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

Automatic Dependent Surveillance – Broadcast Surveillance System Model

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

Airport/TRACON ATC Workload - Sample Concept/Results

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

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

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

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

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

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

Airport/TRACON ATC Workload - Sample Concept Communication System Data

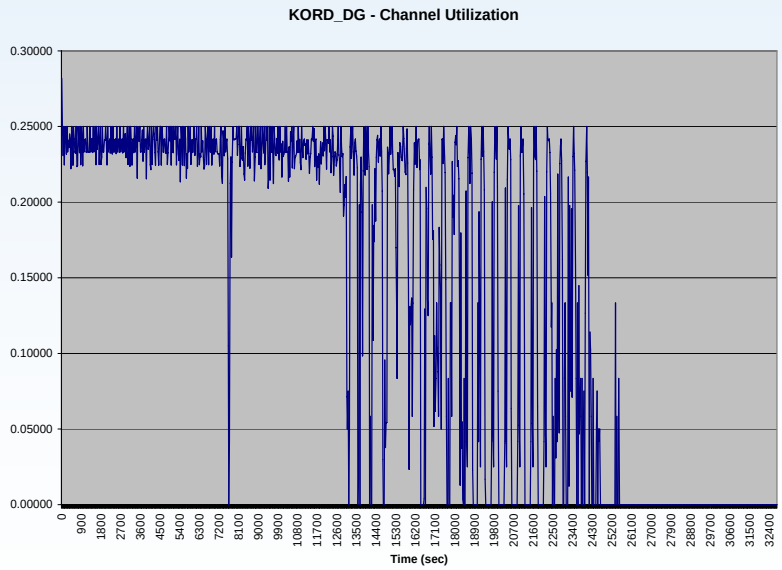
- **Examples of Communications Statistics information stored from each Communications Simulation**

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

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

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

Channel Availability Statistics



Channel Utilization Data

ACES with CNS Models – Potential Improvements

ACES with CNS Models Additions / Improvements

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

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

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

ACES with CNS Models – Summary

ACES with CNS Models offers a wide array of experimentation possibilities

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

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