Self-Separation
Research & Development






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December 6, 2011

Outline

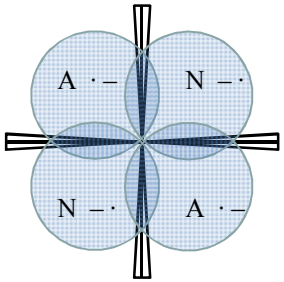
- *Context & motivation for self-separation research*
- *The Autonomous Flight Rules (AFR) concept*
  - Benefits from reduced restrictions
  - Key concept elements
- *Flight-deck automation*
  - Autonomous Operations Planner (AOP) functional overview
- *Research status*
  - Research simulation platform
  - Research overview
  - Results from recent studies (2004-2011)
  - Summary of findings
- *Future plans*

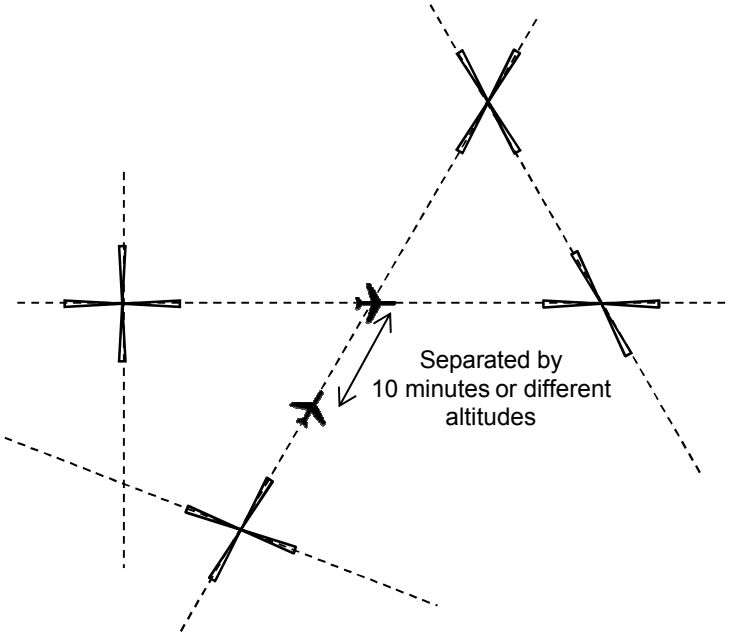
Origins of IFR Flight Restrictions

- *Early IMC navigation limited to a few radio-defined airways*
- *Surveillance by position reports, communications through third party*
  - Led to ATC procedural separation by assignment of route, altitude, speed

➢ *Indirect routes, alt/speed restrictions became the norm*

Four course range





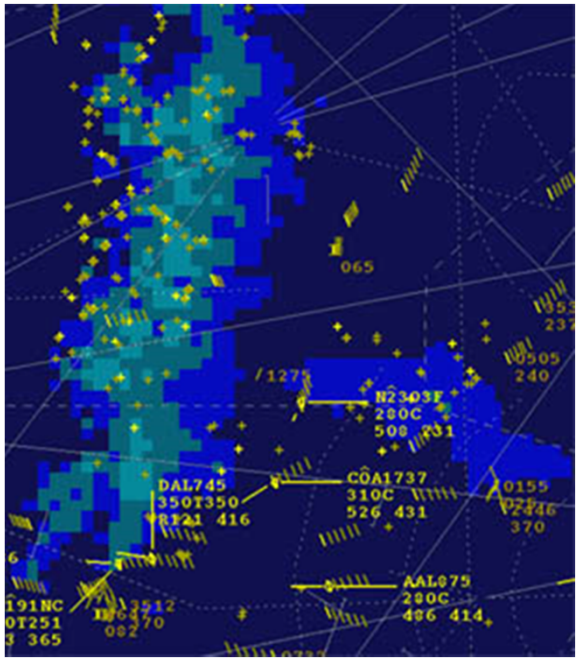
Origins of IFR Flight Restrictions

- *By 1960s – radar, direct pilot/controller comm., RNAV*
  - New technologies enabled reduced separation standards
  - But assignment of route, etc. still the norm

- *Airspace "sector" controller became the limiting factor*
  - Limitations of human cognition demands "orderly" traffic flows
  - Sectors, human capabilities limit numbers of aircraft simultaneously handled
  - Airways, "preferred" routes, cardinal altitudes, "pass back" of delays

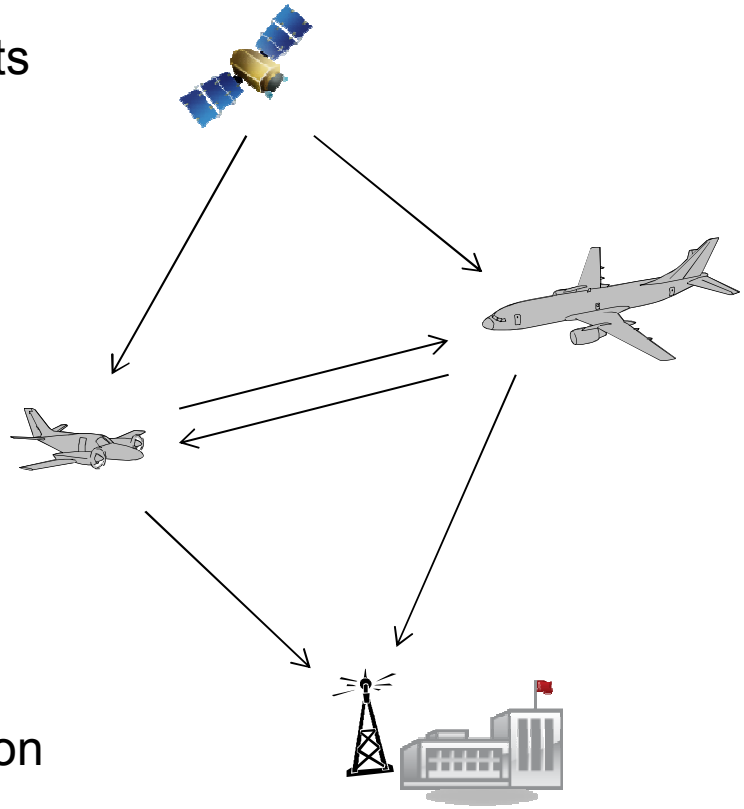
➢ *Restriction, delay, and inflexibility still the norm for IFR*
  - Necessary to enable ATC to maintain responsibility for separation
  - Inefficient routing, non-optimum altitudes, reduced speeds
  - Miles-in-trail spacing, ground delay programs due to en route "congestion"
  - En masse rerouting for weather

Radar display



Maturing Technology Enables Alternative

- *Navigation*
  - GNSS, RNP-RNAV for all-weather, all-points precision navigation
- *Airborne surveillance*
  - ADS-B OUT/IN for high-rate, high-precision air-to-air surveillance
- *Computational capabilities*
  - Onboard automation providing conflict detection, resolution and prevention flight guidance
- *Air-ground data communications*
  - Supplemental airspace and traffic information
  - ANSP coordination
  - Arrival planning



Autonomous Flight Rules (AFR)
A Concept for the Airspace User to Recover Flexibility

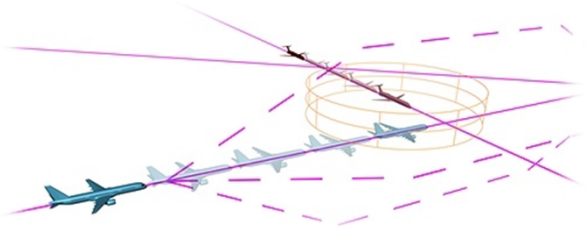
- *A proposed companion to IFR and VFR*
  - IMC (and VMC) alternative to IFR and its costly restrictions
  - "For Spacious Skies" – primarily an en-route concept that leverages the vast capacity of the airspace (ATIO 2011)
  - Self-separation is the enabling capability
  - Removes aircraft from ATC separation responsibility
  - Withdraws aircraft from ATC-related "congestion" that results in many IFR restrictions
  - Designed for non-intrusive mixed operations with all traffic

- *Why a New Rule Set?*
  - Preserve what already works
  - Opportunity to define it properly and uniquely
  - Phase it in gradually
  - Set proper expectations for pilot responsibility

Characteristics of the AFR Concept

Designed to…

- ***… to be safe*** Distributed separation functions and responsibility creates redundancy; Few single-point failures; Employs rigorous rules of coordination
- ***… benefit airspace users*** Eliminates many restrictions and delays of IFR; Provides opportunity for greater flight efficiency and operational flexibility
- ***… work in mixed operations*** Right-of-way goes to existing operation; Facilitates gradual introduction and growth without disruption
- ***… provide immediate benefit*** No minimum participation required; Each equipped aircraft receives benefits and unloads ground system



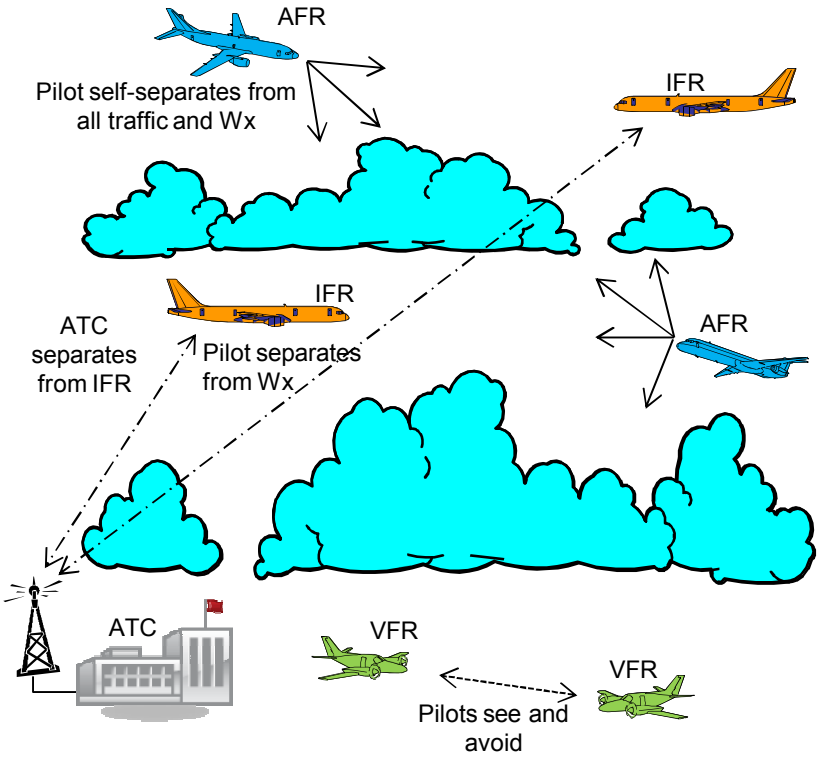
Additional attributes…

- ***Scalable*** Distribution minimizes workload bottlenecks; Enables vastly increased traffic densities (e.g., swarms of UAS)
- ***Minimal costs to ground system*** Primary infrastructure is airborne

Integrated Airspace is Key to Success

True for Any New Operation

- *Segregation has undesired effects*
  - Favors one operation over another
  - Counteracts operational benefits
  - Adds complexity to airspace and operations



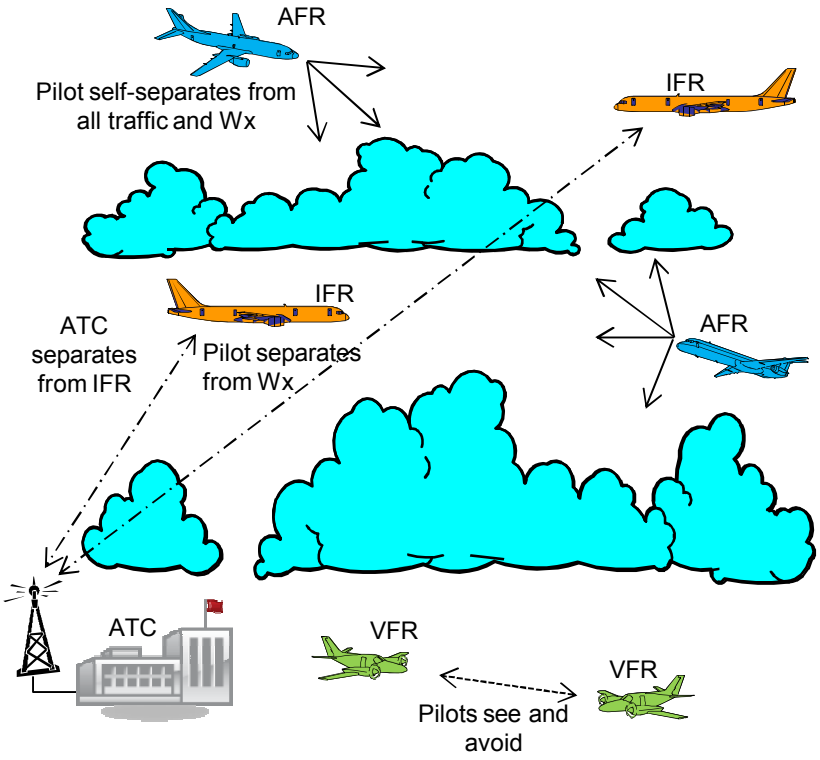
- *Mixed operations are essential to introducing new operation*
  - Investment awaiting "critical mass" is untenable

- *<u>Must-haves</u> of integrated operations*
  - Impact of new operations on existing operations must be <u>minimal to non-existent</u>
  - New operations must generate immediate operational benefit to support investment decision

Integrated Airspace is Key to Success

AFR is designed for Mixed Operations

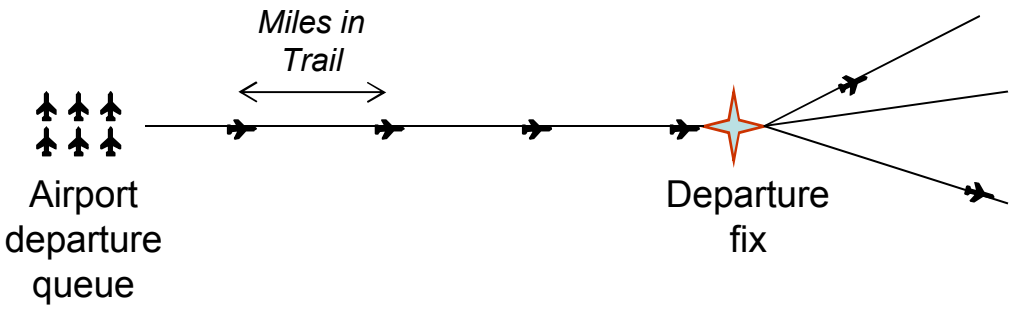
- *AFR enables integrated airspace*
  - Gives right-of-way to IFR in conflicts
  - Maintains extra separation from IFR
  - Essentially transparent to controllers (although not completely)



- *AFR trades small penalty for dramatic benefits*
  - Small penalty:
    - Burdened in conflicts with IFRs
    - Conflicts are few, extra distance is minimal
  - Dramatic benefits:
    - Significantly reduced flight restrictions compared with IFR operations
    - Benefits accrue immediately with first AFR aircraft, and each that follows

AFR Benefits from Reduced Restrictions

IFR ground hold for departure fix saturation



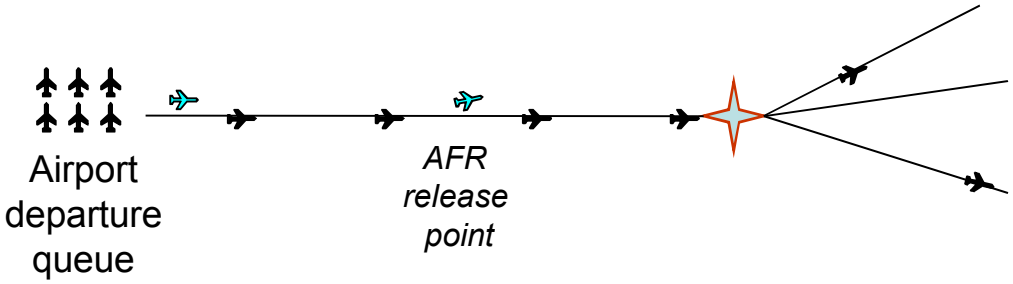
Not to scale

- *IFR flights routed over departure fix*
- *Miles-in-trail restriction imposed by Center on TRACON/Tower*
- *IFR ground hold for miles-in-trail*

➢ *Many additional minutes of taxi-out time waiting for clearance*

➢ *Extra flight distance*

AFR routing not restricted to departure fix



Not to scale

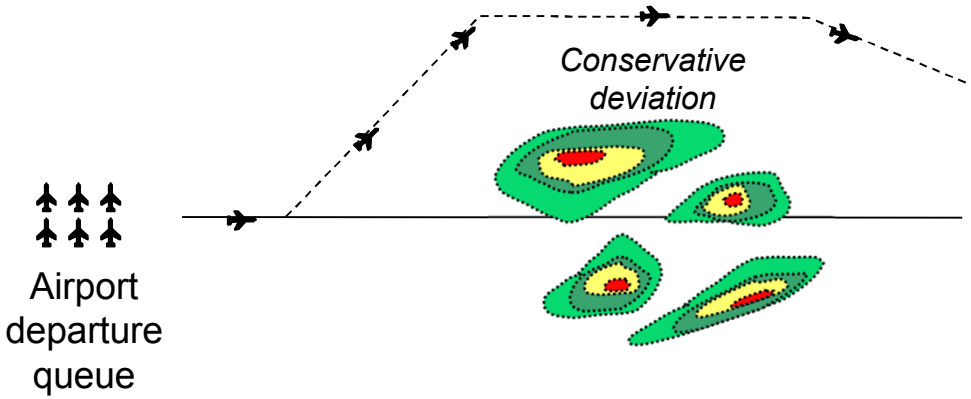
- *AFR does not contribute to departure fix saturation*
- *Miles-in-trail not a factor in departure clearance time*

➢ *Less take-off delay*

➢ *Less flight distance*

AFR Benefits (Continued)

IFR receive severe weather re-routes en-masse

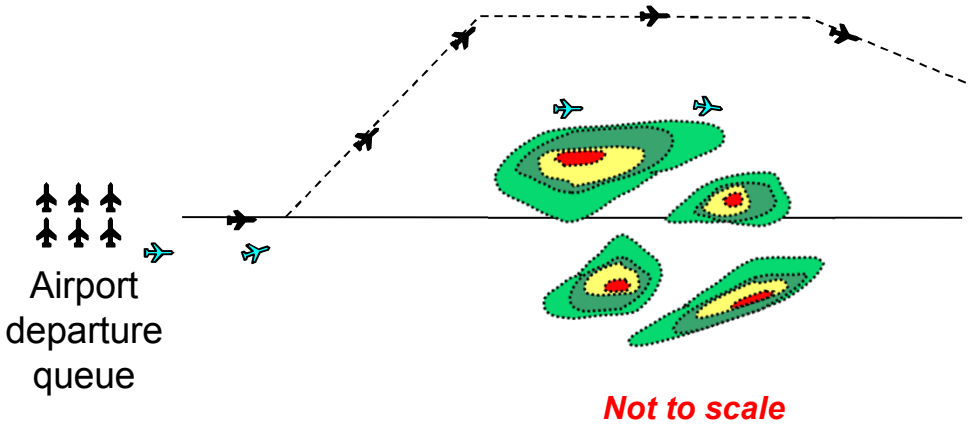


- *Active or forecast convective weather can trigger use of Severe Weather Avoidance Plans (SWAP)*
- *Imposed on IFR aircraft groups*
- *Typically longer than necessary*

➢ *Process of re-clearing IFR flights can cause extensive take-off delay*

➢ *Extra flight distance*

AFR choose own weather avoidance strategy



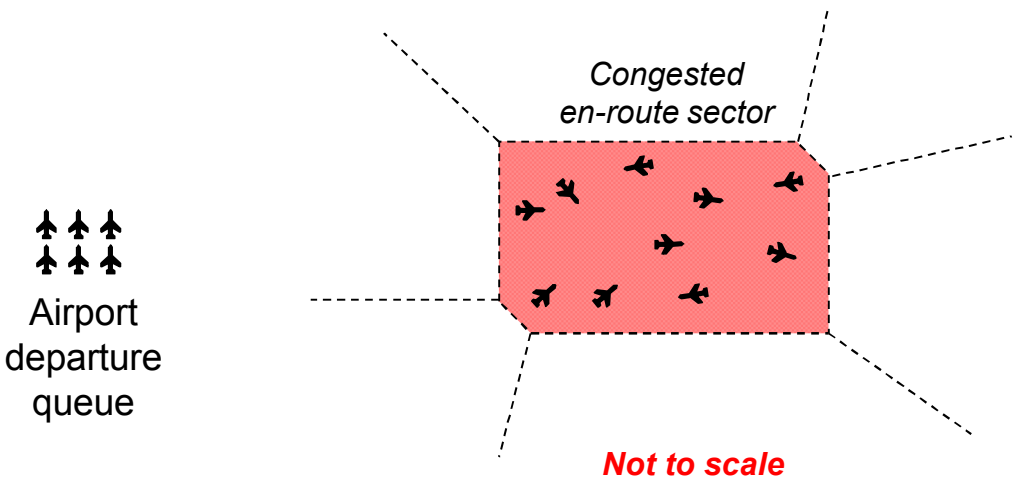
- *Individual flights create individual plans*
- *No need to hold on ground to re-clear with SWAP routes*

➢ *Less take-off delay*

➢ *Less flight distance*

AFR Benefits (Continued)

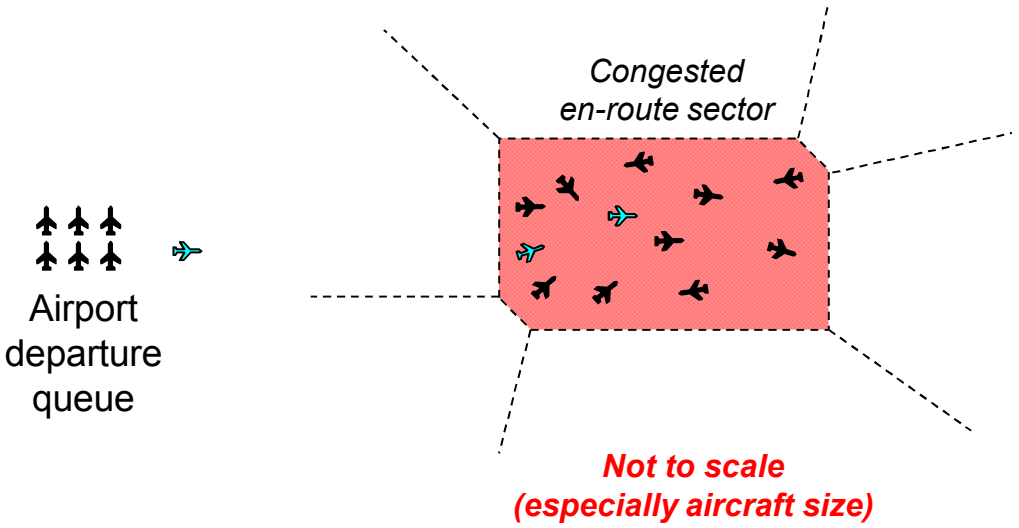
IFR ground delays for en-route sector congestion



- *En-route sector capacity is limited to manage controller workload in monitoring and controlling traffic*
- *Ground delay programs (GDPs) reduce departure flow rates to manage demand*

➢ *IFR aircraft held on ground, or occasionally rerouted*

AFR assumes the burden for its own separation



- *Adds little or no controller workload*
- *Does not contribute to congestion*
- *Significant airspace capacity available*
- *No GDP required for AFRs*

➢ *Less take-off delay*

➢ *Less flight distance*

“Powers of Ten” Exhibits Airspace Scales

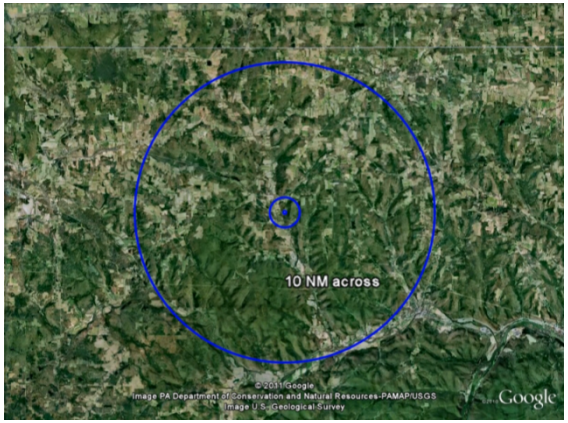
1/10 NM dia.



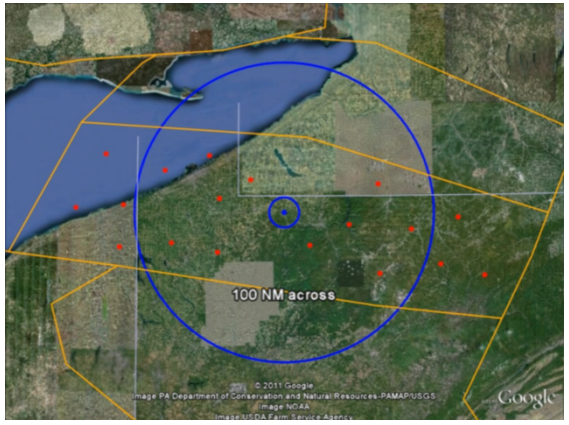
1 NM dia.



10 NM dia.



100 NM dia.

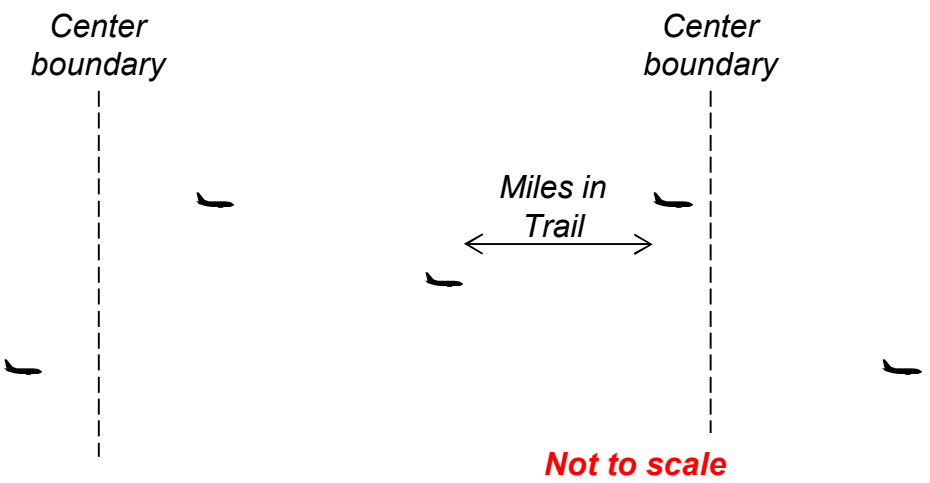


1000 NM dia.



AFR Benefits (continued)

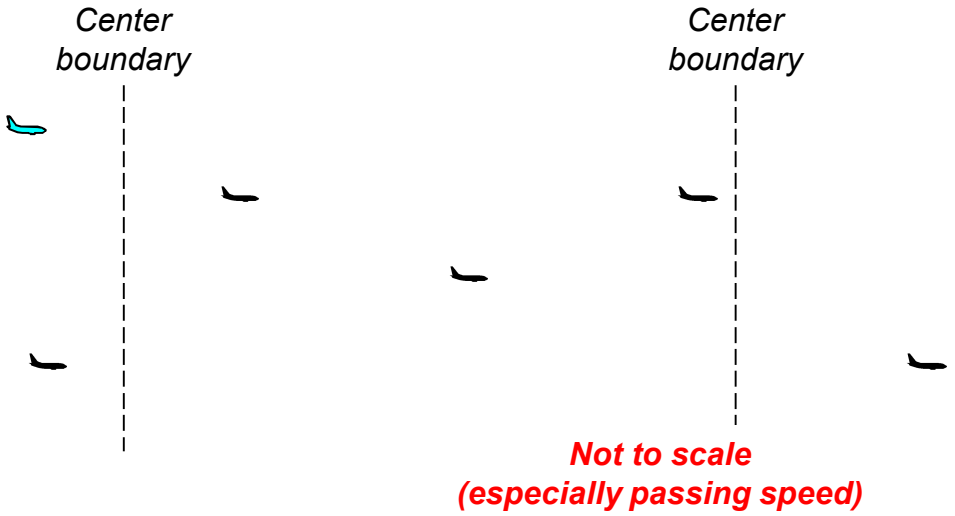
IFR restricted to miles-in-trail crossing Center boundaries



- *Center letters of agreement require 10/15/20 miles-in-trail at Center boundary, regardless of altitude*
- *Prevents aircraft from passing en route due to not enough room and/or speed differential*

➢ *IFRs fly single-file at inefficient speeds or vectored back and forth behind slower aircraft*

AFR maintain best economic or desired speed throughout cruise

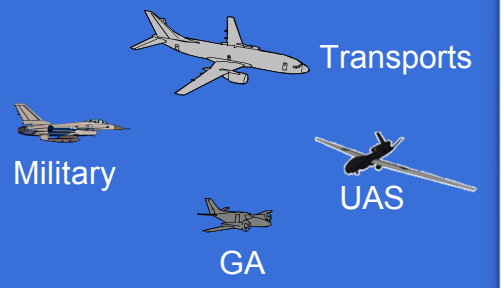


- *AFRs do not contribute to Center congestion*
- *Plenty of airspace to pass while maintaining separation*
- *Merged with IFRs in terminal airspace*

➢ *Optimum fuel economy over long distance*

The Key Elements of AFR Operations

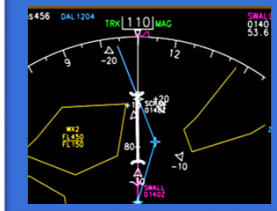
AFR Operators



Infrastructure

1. *ADS-B & TIS-B for surveillance*
2. *SWIM & CPDLC for communications*

AFR Automation Tool



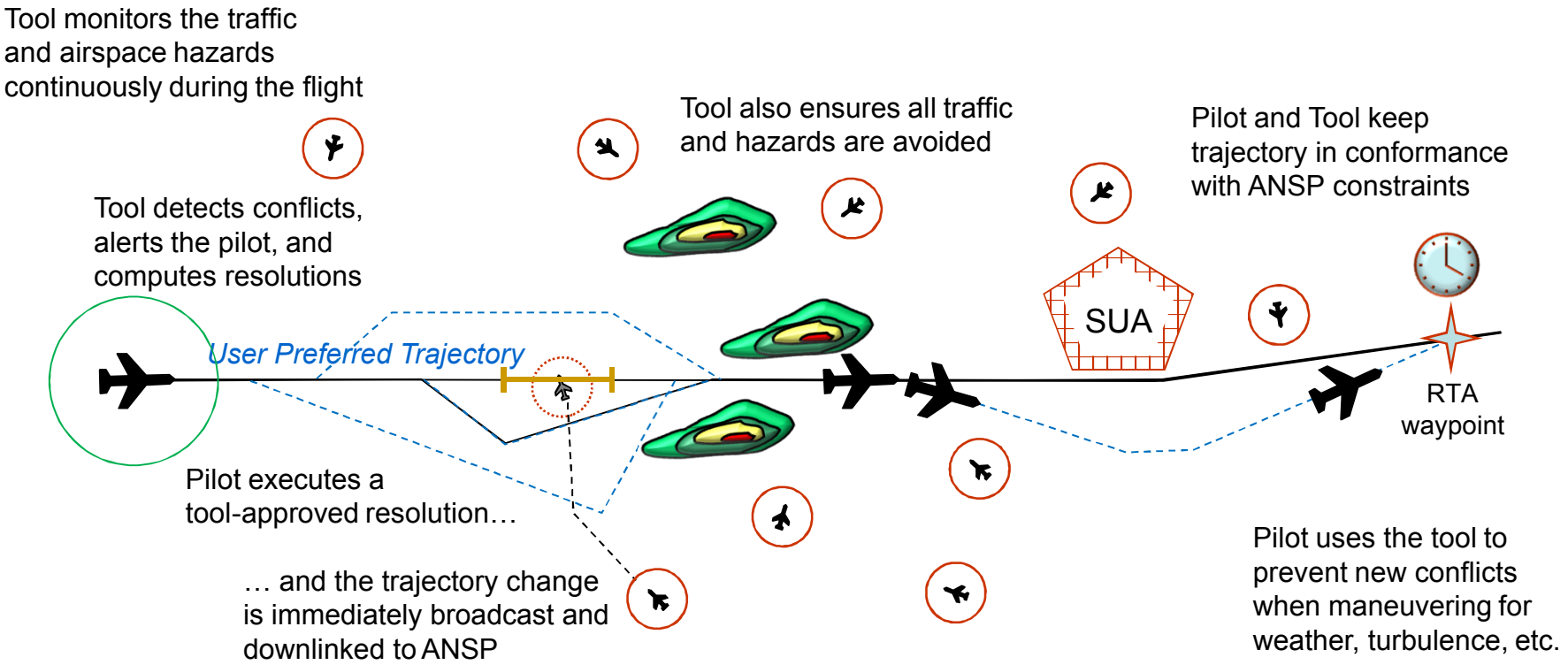
Integrated Operations

1. *IFR has right-of-way*
2. *AFR coordination of burden and maneuvers*
3. *VFR see-and-avoid*
4. *ANSP arrival scheduling*

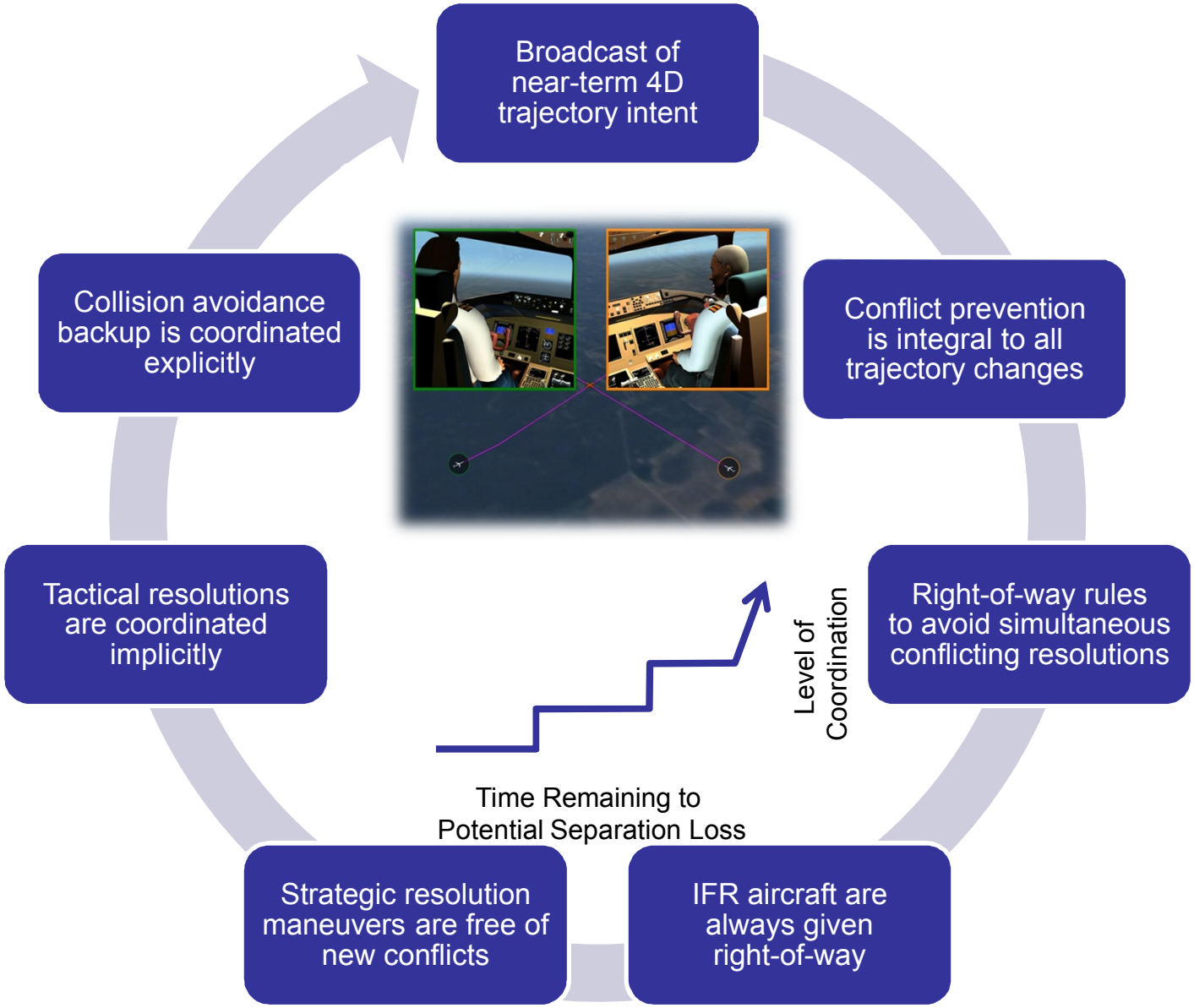
AFR Pilot Rules & Procedures

1. *Separate from traffic*
2. *Maneuver w/o conflict*
3. *Fit into ANSP TFM plan*

The Key Elements of AFR Operations



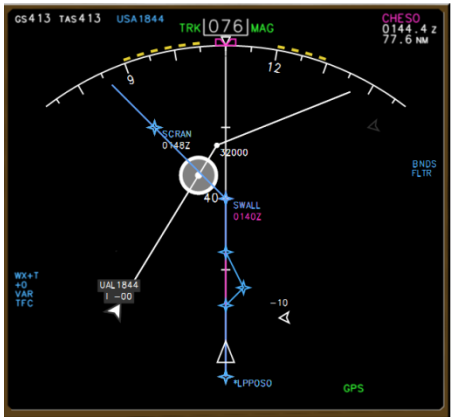
Coordination
Among Aircraft, and with Ground

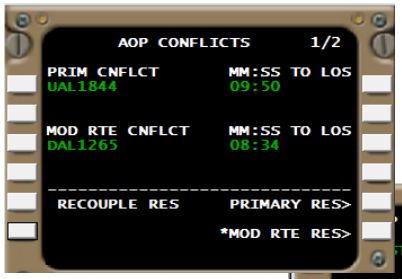


Avionics Technology for Self-Separation
NASA "Autonomous Operations Planner" (AOP)

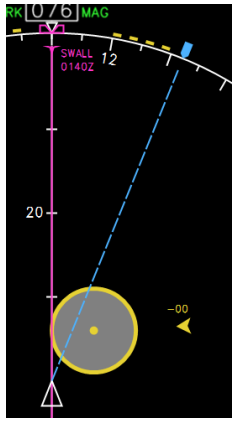
- ***Integration of self-separation and 4D-TBO functionality***
  - Traffic separation in FMS and MCP flight modes
  - Optimization of trajectories (integrated with de-confliction)
  - Trajectory constraints conformance
  - Provisional probing for conflict-free trajectory changes
  - Implicit coordination with traffic aircraft actions

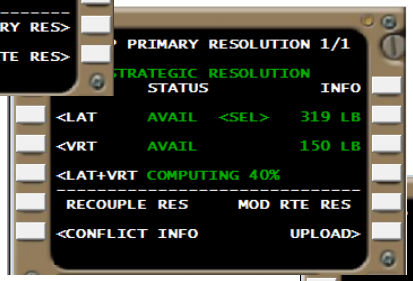


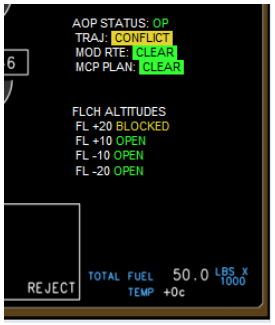


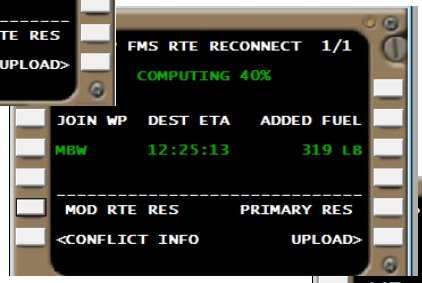




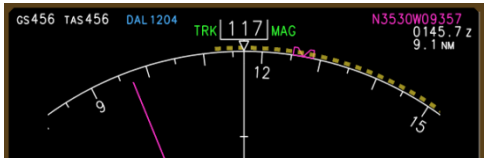


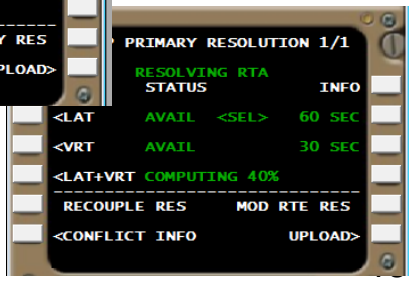






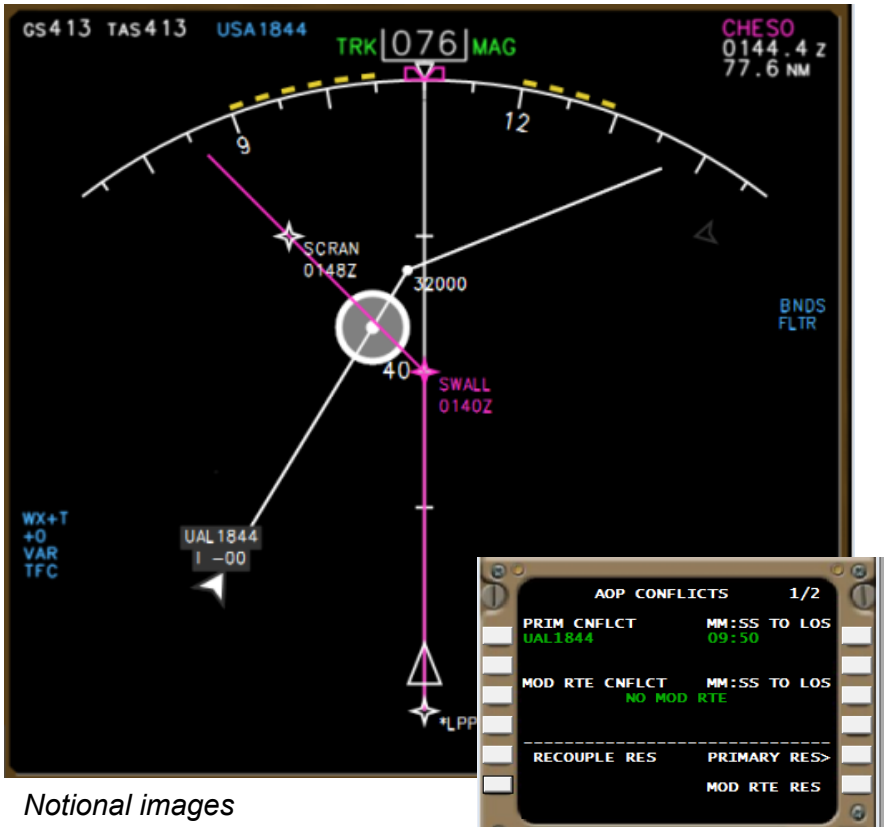






Avionics Technology for Self-Separation
NASA "Autonomous Operations Planner" (AOP)

Conflict Detection

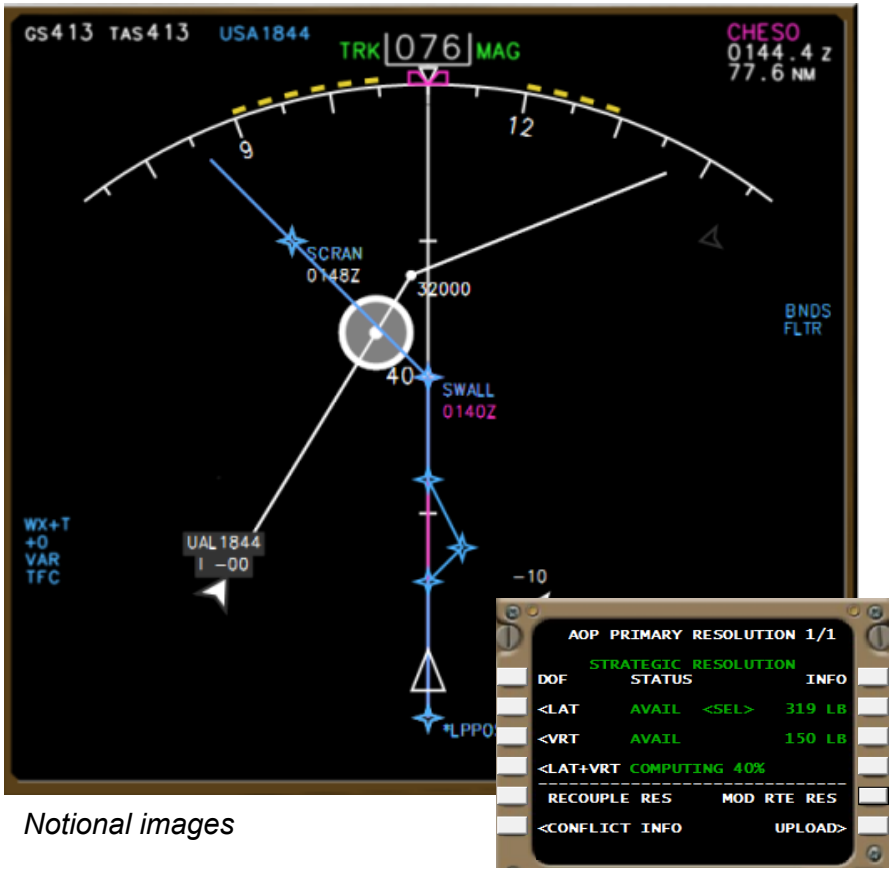


Notional images

- *Intent-based and adaptable*
  - 4D trajectory intent
  - Target-state intent
  - State vector (no intent)
- *Complex ownship flight modes*
  - Monitors auto-flight settings
  - Pure and mixed MCP/FMS modes
- *Prediction uncertainty handling*
  - 4D volumetric uncertainty bounds
  - Customized per trajectory segment
- *Priority-based alerting*
  - Right-of-way coordination

Avionics Technology for Self-Separation
NASA "Autonomous Operations Planner" (AOP)

Strategic Conflict Resolution

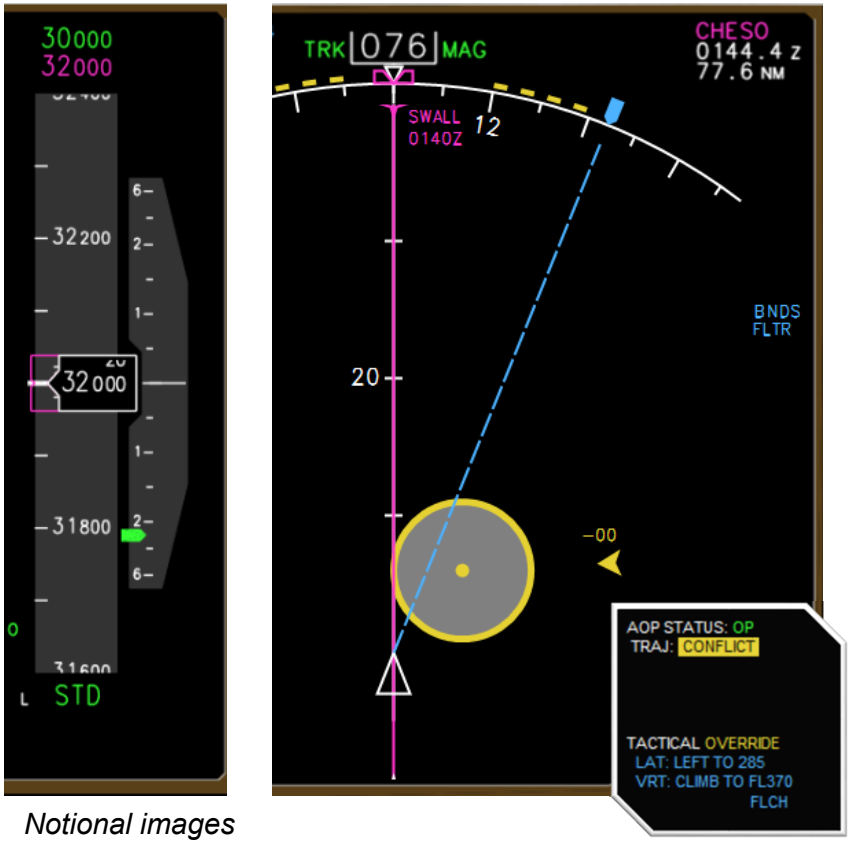


Notional images

- *FMS integrated*
  - Trajectory-based solutions
  - High-fidelity performance model
  - Lateral, vertical, combined options
- *Solver of complex mixed constraints*
  - Traffic, area hazards, crossing restrictions (e.g. RTA)
  - Simultaneous solution method
    - Pattern-based genetic algorithm
  - Minimized relaxation of non-safety constraints (RTA, weather buffer)
    - Only if needed
- *Flight optimization*
  - User customized criteria
  - Min fuel, or min time, or min distance

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NASA "Autonomous Operations Planner" (AOP)

Tactical Conflict Resolution

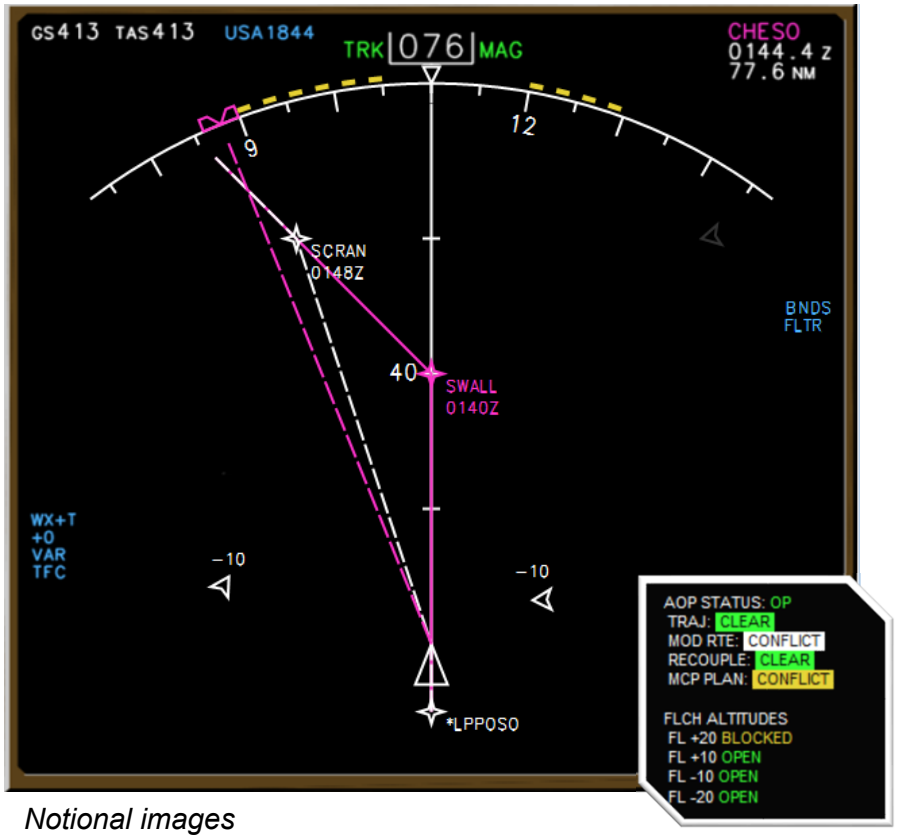


Notional images

- *MCP integrated*
  - HDG / Track / FLCH / VS solutions
  - Turn and climb dynamics
  - Lateral, vertical options
  - Pilot-selected and override modes
- *Solver of complex mixed constraints*
  - Traffic, area hazards
  - Intent-based resolutions
  - Quick response, dynamically updated
- *Implicit coordination with traffic*
  - Conforms to coordination criteria
  - Transitions to state-based LOS recovery logic (one-on-one maneuver)

Avionics Technology for Self-Separation
NASA "Autonomous Operations Planner" (AOP)

Trajectory Change Planning

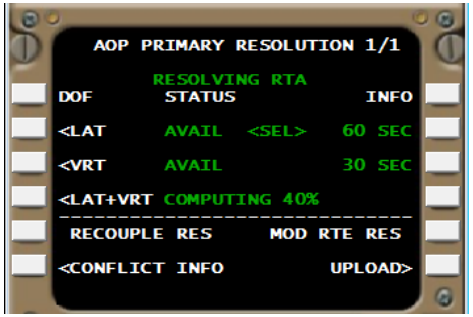


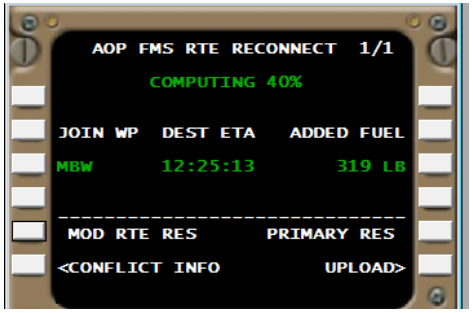
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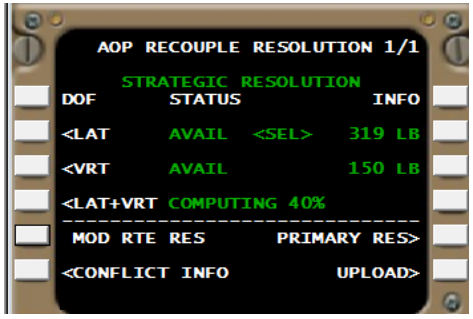
- *Conflict predictor for planning*
  - FMS MOD routes
  - MCP tactical maneuvers
  - Flight mode changes
  - "What if…"
- *Maneuver Restriction (MR) bands*
  - At-a-glance info on available options
  - Track bands
  - Vertical speed bands
- *FLCH altitude probe*
  - Similar to MR bands
  - Sweep of nearby altitude changes
  - Includes climb/descent paths

Avionics Technology for Self-Separation
NASA "Autonomous Operations Planner" (AOP)

Strategic Support Functions







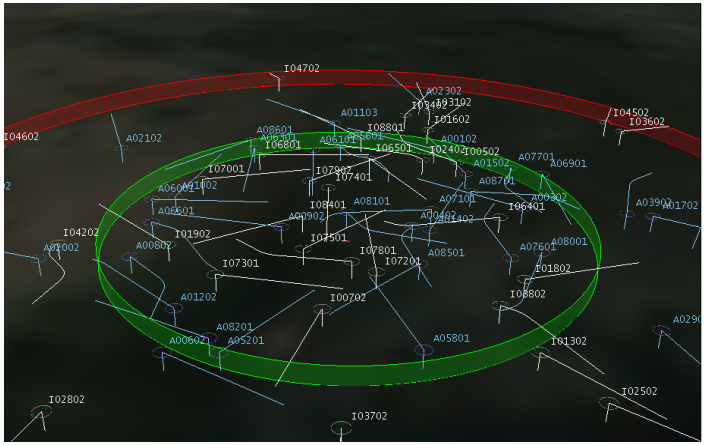
Notional images

- *Conforming to RTA / arrival delays*
  - Resolves "unmet" RTA constraint
  - Path stretch and short-cut solutions
  - Conflict free
- *Rejoining the FMS route*
  - Reconnect following a tactical maneuver
  - Conflict free
- *Changing flight modes*
  - Engaging LNAV and VNAV
  - Conflict free

AOP Technology Maturity

- ***Tested in batch simulations with extreme high traffic density***
  - Up to 10x traffic density
  - Fully randomized geometries
  - Pilot delay effects
  - Wind uncertainty effects
  - ADS-B range and interference effects
  - Dynamic weather/traffic avoidance

Batch Simulations for Stress Testing

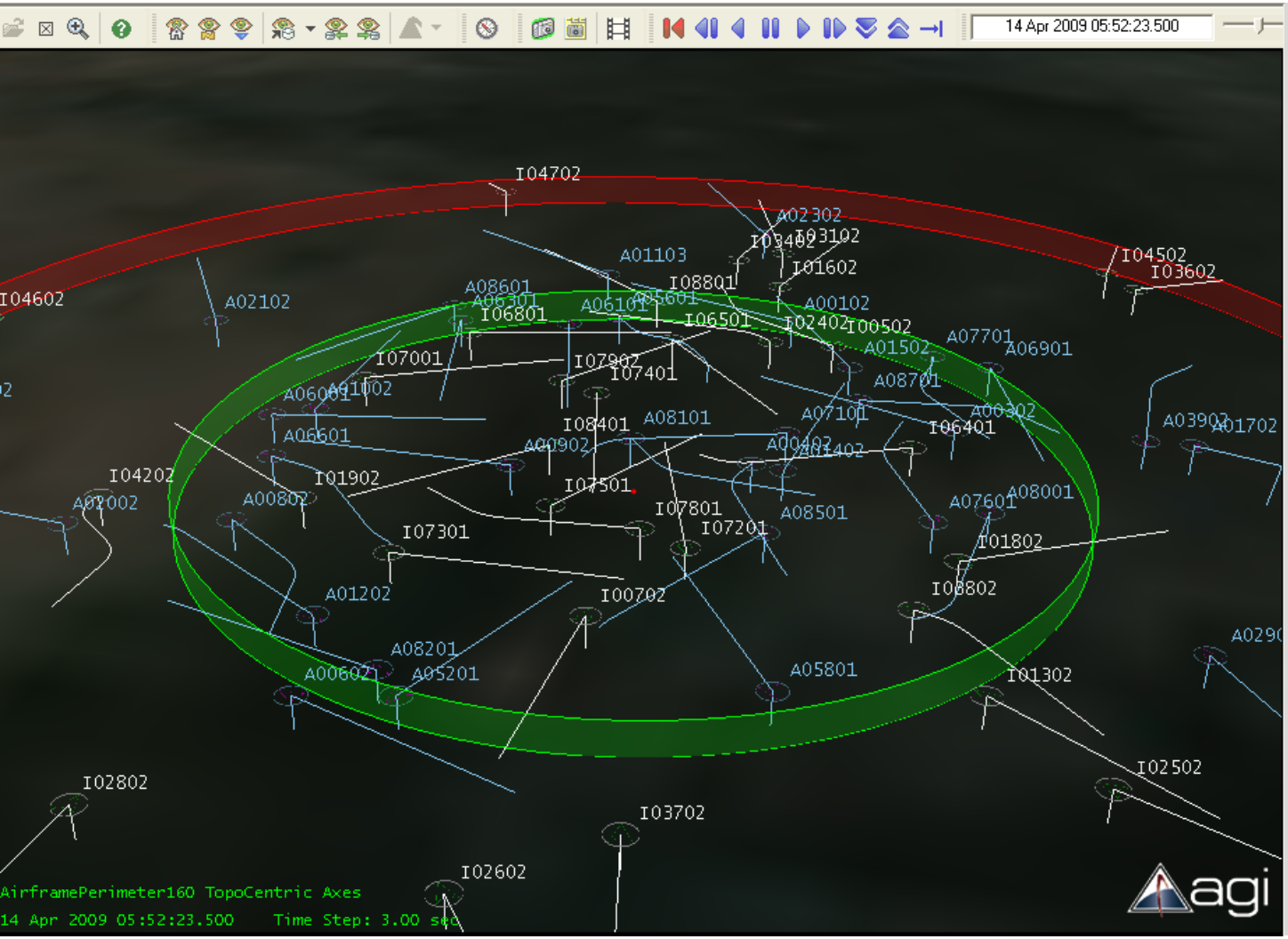


- ***Tested with procedures in challenging and dynamic HITL simulations***
  - Simultaneous traffic & flow constraints
    - Required Time of Arrival (RTA)
  - Strategic and tactical separation
  - Mixed operations
    - AFR and IFR in shared airspace
  - Arrival delay path-stretching

HITL Simulations for Operations Testing



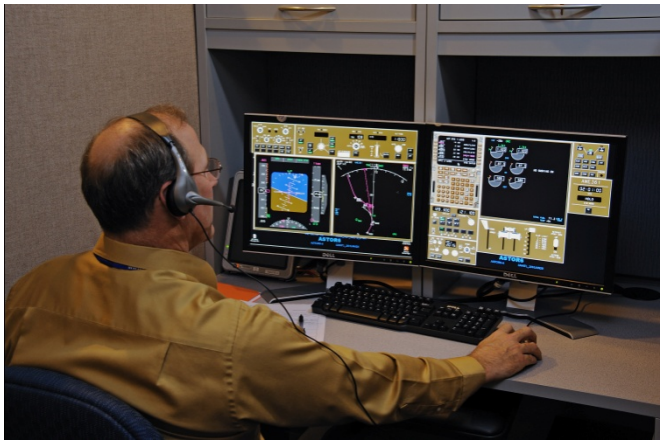
Stress-Test Batch Platform



Self-Separation Batch Test Environment

- *160 NM dia. generic circular airspace*
- *Traffic density 1x to 12x (or more)*
- *Altitude range: 1 to many Flight Levels*
- *Random encounter geometry*
- *Random surrounding traffic*
- *RTA constrained*
- *Real-time AFR interactions*
- *Models*
  - Pilot action delay
  - Wind prediction error
  - 1090ES range & interference
  - Weather hazards

HITL Platform for Operational Testing







Self-Separation HITL Environment

- *Air Traffic Operations Lab*
- *Same software as batch platform*
- *12 part-task, single pilot stations*
- *Accurate displays and controls for modern Boeing jet*
- *100's of additional "pilot model" aircraft*
- *Real-time ADS-B surveillance of traffic*
- *Realistic airspace & traffic scenarios*
- *RTA assignments received over data link*
- *ATC station integration and testing in progress*

NASA Self-Separation R&D Status

Depth of Accomplishments

R&D Elements	Addressed	Future
ATM and aircraft infrastructure	ADS-B 1090ES model; Medium-fidelity glass cockpit; ARINC 429 avionics architecture modeling	Backup surveillance (TIS-B); IFR intent source (SWIM?); Weather data (4D Wx Cube?)
Flight-deck automation	Separation functions; 429 avionics integration (FMS, MCP, EICAS, MCDU, ND, PFD)	EFB implementation; Complexity mitigation
Pilot and controller procedures	Nominal en-route; Strategic & tactical operations; Basic arrival coordination (RTA); Mixed ops (prelim.)	Off-nominal procedures; Full mission environment; CRM; Arrival transition w/ sep. responsibility transfer
Coordination	Multi-layered design; Right-of-way rules; Robust maneuver coordination; Mixed operations (nominal)	Limited or no traffic intent; Mixed operations (off-nominal)
Environmental factors	Winds; Wind prediction errors; Dynamic weather avoidance (algorithms)	Dynamic weather avoidance (interface & procedures)
Human factors	Display/interface design; Pilot response delay; Pilot non-responsiveness	Automation trust issues; High workload scenarios; Two-pilot crew coordination
Traffic scenarios	Scalability; Random geometries; Realistic scenarios; RTAs; Delay absorption; Area hazards	Lower altitude operations; Transition to & from IFR
Integration	TFM services (arrival scheduling); Flow corridors; AFR/IFR mixed operations (nominal)	AOC; Terminal operations; AFR/IFR mixed operations (off-nominal)
Safety	Layered safety design; CD&R w/ proven properties; Algorithm stress-testing; HITL safety ratings	Operational safety assessment; Off-nominal scenarios
Benefits / Costs	Single-year benefits; Lifecycle benefit/cost (analyses were pre-JPDO)	Updated system-level assessments; Operator-based assessments; Gate-to-gate / fleet ops

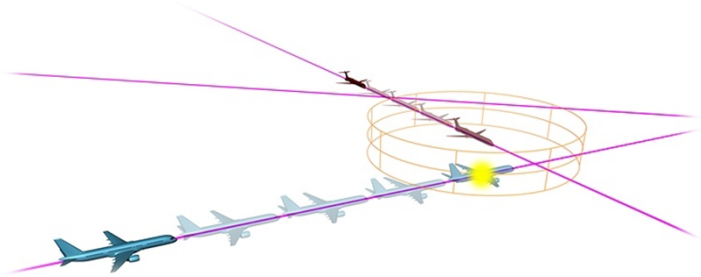
Key Research Issues Initially Addressed

Traffic Scalability
How much traffic density and traffic complexity can self-separation handle?

Human Perspective
How does the quantity of self-separating traffic affect pilot & controller acceptability?

Air/Ground Comparison
How does AFR compare to ground-based automated separation assurance?

Pilot Response Time
How critical is it that pilot actions be timely and complete?



Wind Uncertainty
How accurate must wind predictions be to maintain integrity of self-separation?

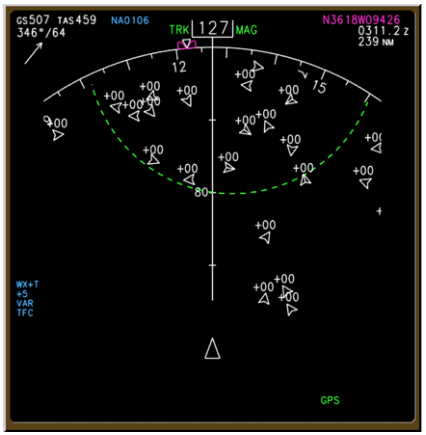
Surveillance Limitations
How do ADS-B range and interference affect self-separation performance?

Weather Integration
How is traffic separation safety affected by dynamic weather hazards?

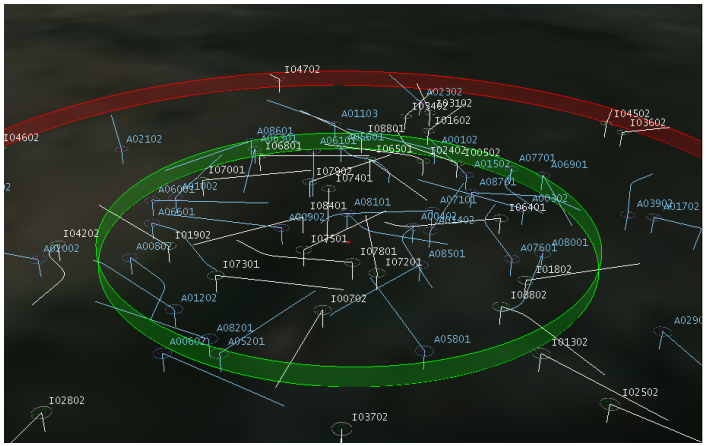
Intent Information Criticality
How critical is intent sharing to mixed operations?

Traffic Scalability
2007 SPAS Baseline Batch Study

Issue	Self-separation is fundamentally scalable by its distributed design, but safe scaling limit is unknown
Objective	Determine limit of scalability
Approach	Batch study, random lateral encounters, strategic lateral CD&R only, varied traffic density
Key metric	Loss of separation (LOS) frequency
Results	Scalability limit not reached (>10x)



Batch "Stress Test" Scenario



Disclaimer:
Results not conclusive proof of safety performance!

Strategic CR Only – No Tactical CR Backup

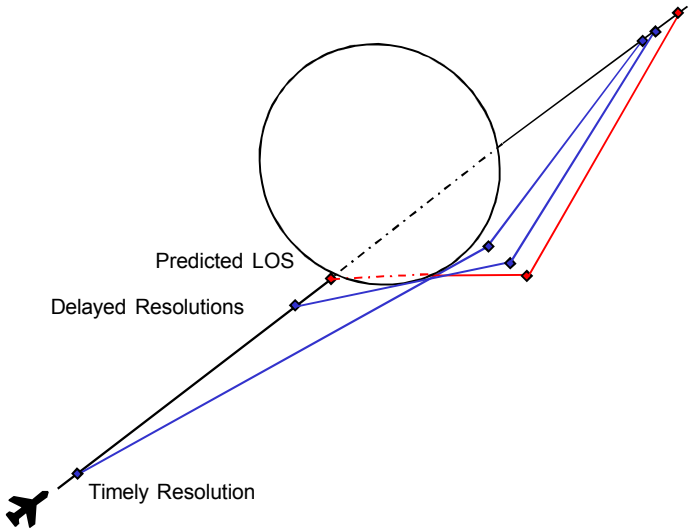
2x ** … 10x

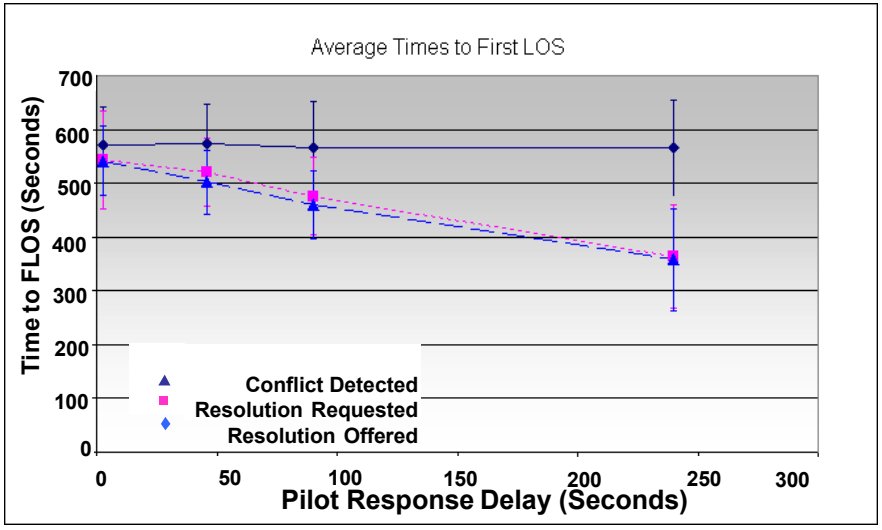
Sustained Mean Density*	Sim. Hours	Simulated flights	Traffic conflicts	LOS
3.45	36	881	195	0
6.11	36	1527	550	0
8.61	36	2195	1018	0
11.64	36	3000	1788	0
15.24	12	1302	963	0
17.18	12	1560	1256	0
Totals	**168**	**10,465**	**5770**	**0**

*Aircraft per 10,000 NM² **Ref. sector ZOA31, FL310, 19 Feb 2004

Pilot Response Time
2008 SPAS Pilot Delay Batch Study

Issue	Human involvement in separation is a key safety benefit of self-separation, but response time may have impact
Objective	Determine effect of pilot delay
Approach	Batch study, random encounters, high density traffic, pilot action delay model
Key metric	Loss of separation (LOS) frequency
Results	Self-separation is tolerant of pilot response variability (i.e., decision-making time) Measurable effects seen at extreme traffic densities and substantial pilot delays





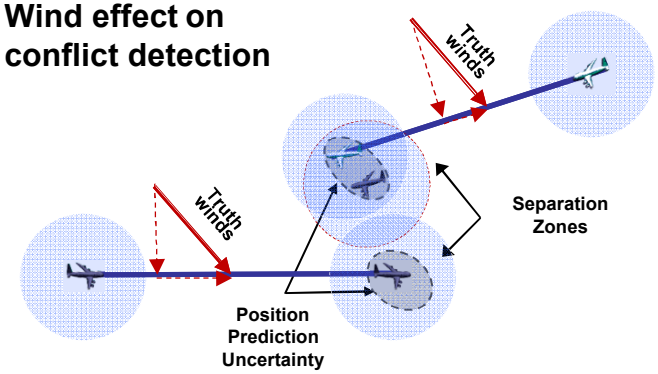
Strategic CR Only – No Tactical CR Backup

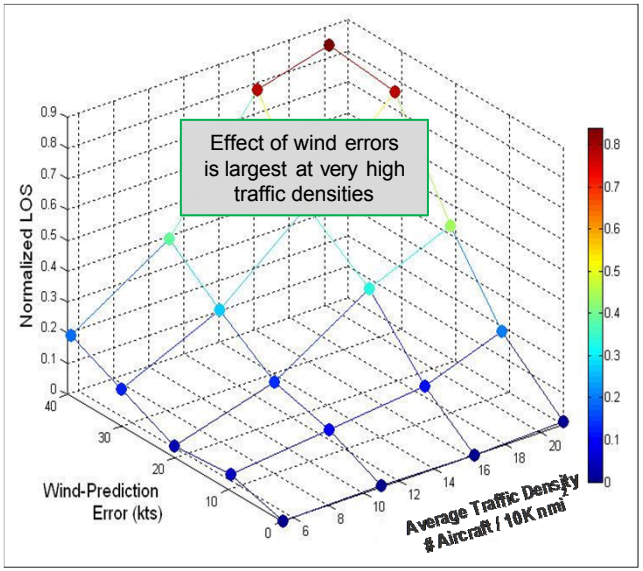
Aircraft per 10000 nmi²	Average Pilot Delay (sec)	Total Flight Hours	Total Conflicts	Total LOS	LOS/ 1000 Flight Hours
21.4 ~12x Ref. 2004 mean density	3.5	572.6	2307	2	3.4
	46	115.1	484	1	8.7
	90	577.5	2463	7	12.1
	240	117.4	514	10	85.2
	All Runs	**1382.6**	**5768**	**20**	**14.5**

Prediction Uncertainty
2009 SPAS Wind Error Batch Study

Issue	Wind prediction error is a primary uncertainty in trajectory modeling for separation automation
Objective	Measure the effect of wind prediction error and determine the additional buffers required Cruise flight, lateral effects only in this study Vertical effects known to be significant (future work)
Approach	Batch study, random encounters, high density traffic, winds unknown to AOP Traffic densities: 3x, 5x, 9x, 12x Wind prediction errors (kts): 0, 10, 20, 30, 40
Key metric	Loss of separation (LOS) frequency (LOS/flight hour)
Results	Small buffers can compensate for moderate wind errors

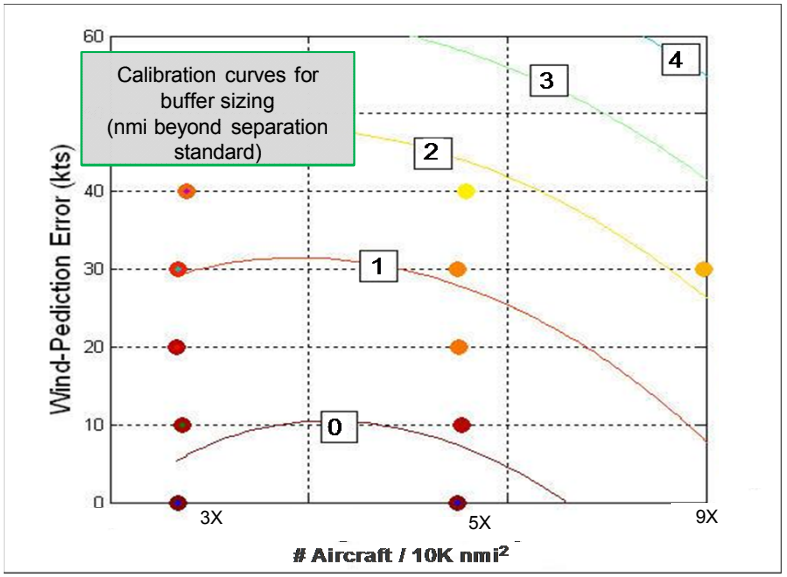
Wind effect on conflict detection





Strategic CR Only

No Tactical CR Backup

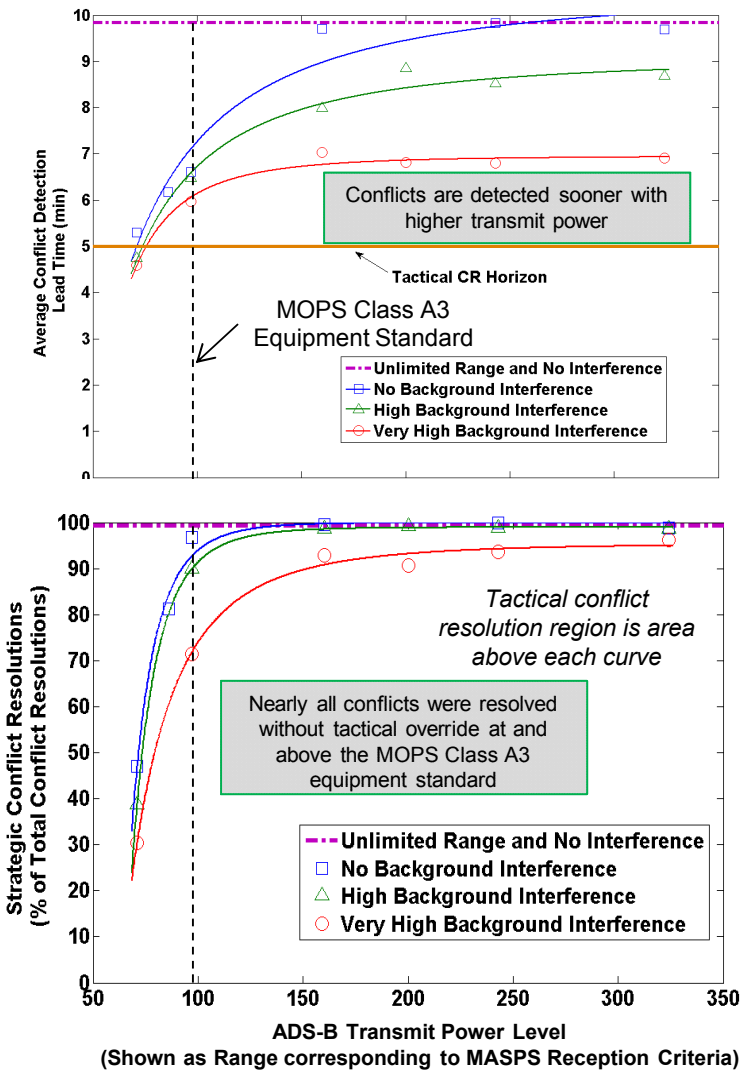


Surveillance Limitations
2010 CRISP Batch Study

Issue	Self-separation is enabled by ADS-B surveillance, which has its own limitations
Objective	Assess impact of 1090 surveillance range limits and dropped messages on strategic CD&R
Approach	Batch study, cylindrical scenario, randomized high density traffic, varied transmit power and background 1090 MHz interference (FRUIT) Transmit Power (effective range): 71 nm to 324 nm Interference (rel. 2035): 0, 2x (high), 3.6x (very high)
Key metrics	LOS frequency, conflict detection time, % resolutions not requiring "tactical override"
Results	LOS very low; not enough to identify trends Larger surveillance range results in fewer conflicts, fewer trajectory changes, more efficient routing Traffic density not a significant factor

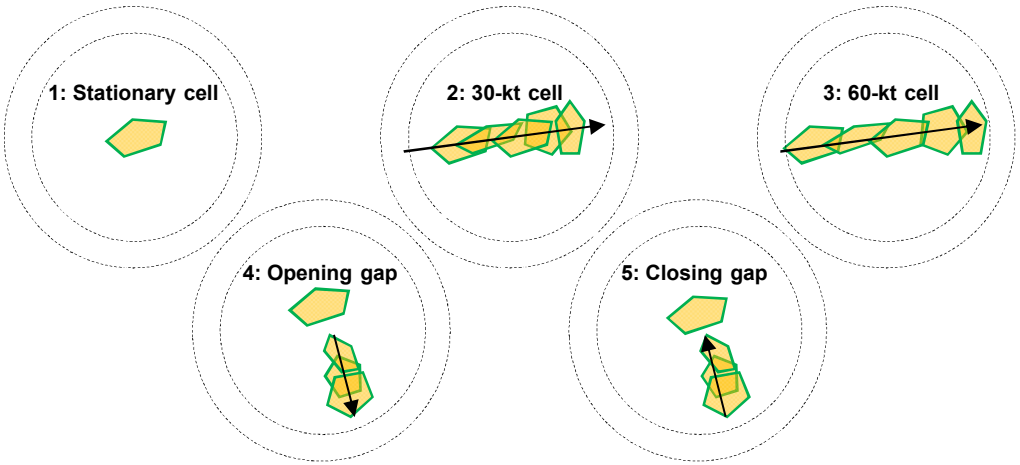
Sustained Mean Density (ref. 2004)	Conflict Detections	Losses of Separation	LOS/ 10000 Conflict Detections
3.73x	9142	0	0
4.97x	17323	3	1.7
7.46x	42427	13	3.1
Totals	**68892**	**16**	**2.3**

Strategic CR with Tactical CR Backup

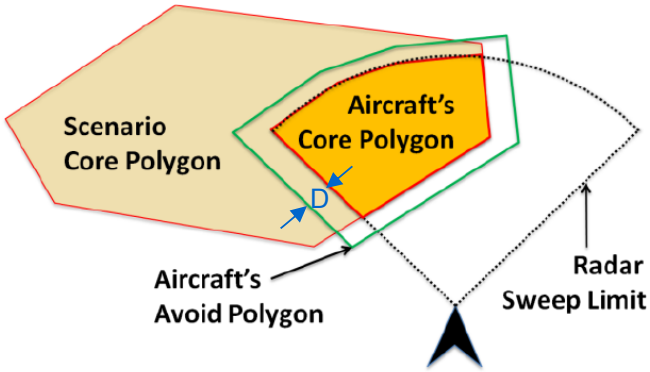


Weather Integration
2010 WISP Batch Study

Issue	Weather significantly reduces airspace capacity in current-day operations. How does weather avoidance impact self-separation from traffic?
Objective	Investigate interaction of traffic separation and dynamic weather hazard avoidance
Approach	Batch study, cylindrical scenario, randomized high density (2x) traffic, dynamic weather polygons, simulated onboard Wx radar, strategic & tactical CD&R
Key metrics	Loss of separation, weather penetration
Results	Wx avoidance strategy effective over wide range of weather patterns and cell speeds Avoid polygons 2-3 nm larger than core are sufficient to account for most uncertainties Traffic separation not degraded by Wx avoidance



Simulated Onboard Wx Radar



Automated weather avoidance capability provides crews with conflict-free trajectories compliant with RTA constraints

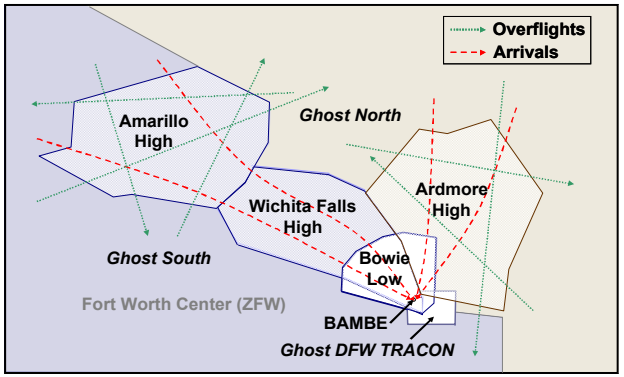
Strategic CR with Tactical CR Backup

Weather Pattern	LOS D=1nm D=2nm D=3nm	Core Area Penetrations		
		D=1nm	D=2nm	D=3nm
Stationary cell	0	2	4	0
30-kt cell	0	2	0	0
60-kt cell	0	16	0	0
Opening gap	0	2	2	2
Closing gap	0	14	5	9

Human Perspective

2004 Air-Ground Joint Simulation (Langley & Ames)

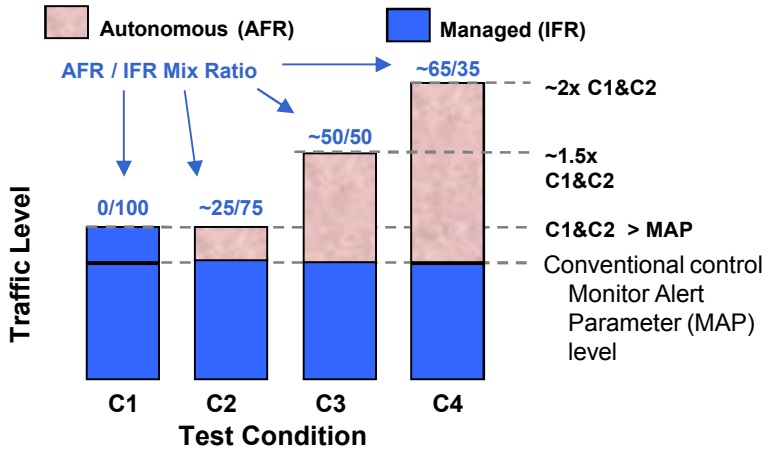
Issue	The scalability of AFR operations can be affected by human procedures and perceptions
Objective	Assess the impact of introducing AFR operations and increasing their quantity
Approach	HITL study, subject pilots and controllers, en route and arrival airspace, metering
Key metrics	Loss of separation, arrival time conformance, pilot and controller workload, acceptability
Results	Very few AFR LOS's, did not vary with traffic level AFR arrival time conformance was high Controller workload lower for mixed conditions even at higher traffic levels Safety concerns raised over near-term conflicts

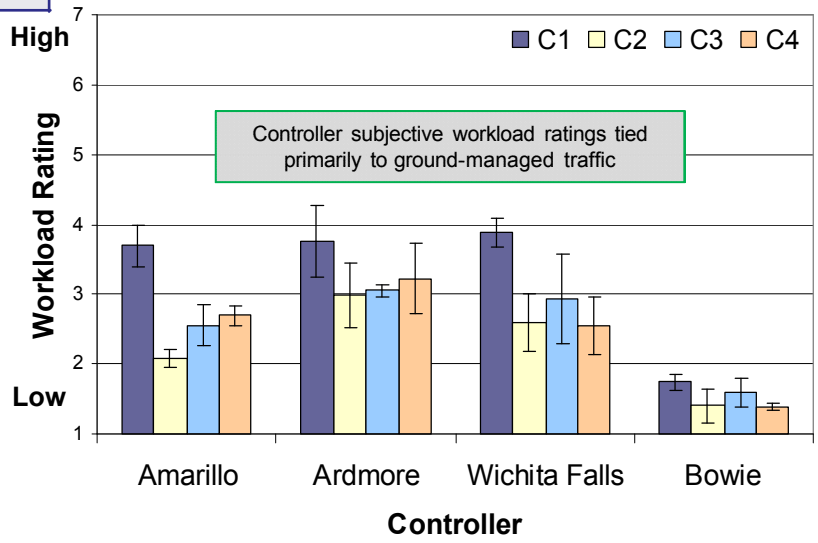


Controllers at Ames



Pilots at Langley & Ames





Air / Ground Function Allocation Baseline

2010 HITL Commonality Sims (Langley & Ames)

Issue	Disparate separation concepts proposed for NextGen; how do we compare and then integrate in mixed operations?
Objective	Compare performance as baseline for future studies of mixed operations and off-nominal conditions
Approach	Two HITLs with common expt. designs, scenarios, metrics, data analyses
Key metrics	Several safety, efficiency, and subjective metrics
Results	Partial comparison was achieved – No major differences in nominal conditions – Performance differences were subtle – Refinements needed before mixed operations

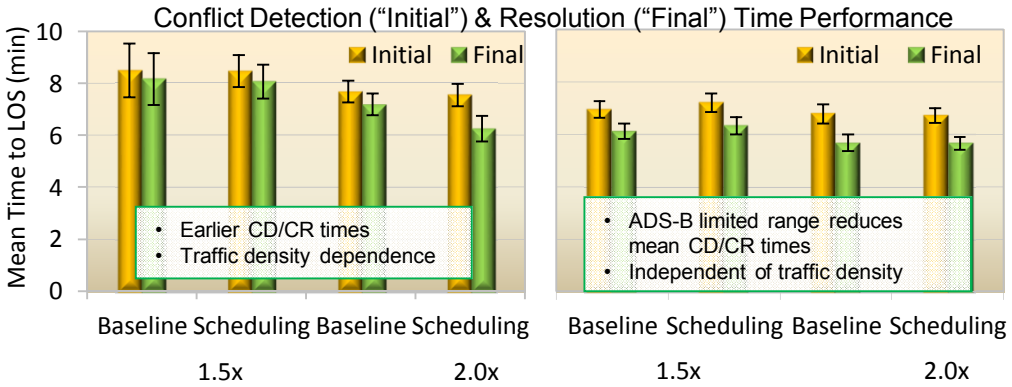
Commonality of Experiments	Necessary Differences
Modeled airspace	Concept assumptions
Traffic scenarios	Human subject participants
Metering assignments	Human subject quantity
Independent variables	Participation time & training
Duration of runs	Subject aircraft quantity
Definitions of key metrics	Handling of non-subject aircraft
Data analysis methods	Automation system design

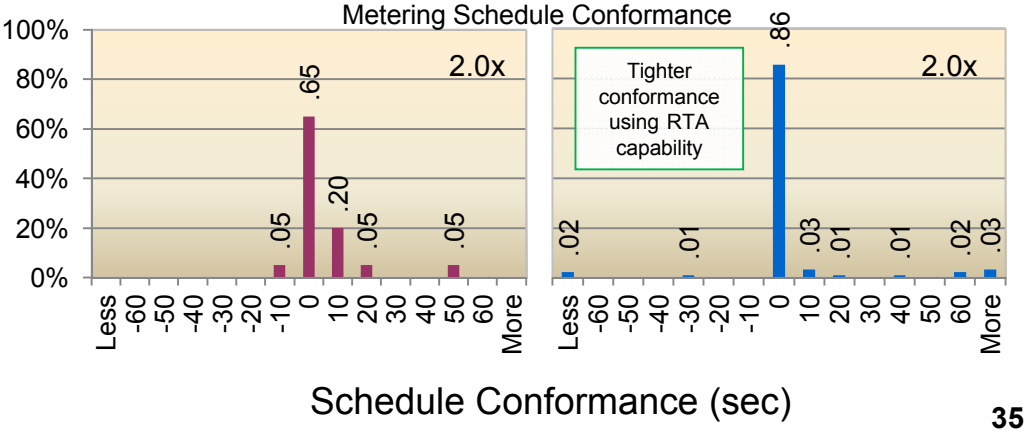


Ground-based SA Experiment



Airborne SA Experiment





Summary
Findings Emerging from Self-Separation Research

- ***Highly scalable with traffic demand***
  - Sustainable far beyond current projections, even without complexity management initiatives
- ***Compatible with highly-complex traffic environments***
  - High traffic densities, unstructured flows, random conflict and traffic geometries, time constraints, airspace hazards
- ***Tolerant of real-world, imperfect conditions***
  - Human response variations, prediction uncertainties, surveillance system limitations
- ***Integrates with current systems***
  - Flight-deck systems, operations, procedures
  - Mixed operations w/ ground-managed aircraft
- ***Very satisfactory to pilots in simulations***

Summary
Recommended Further Research

Prior research

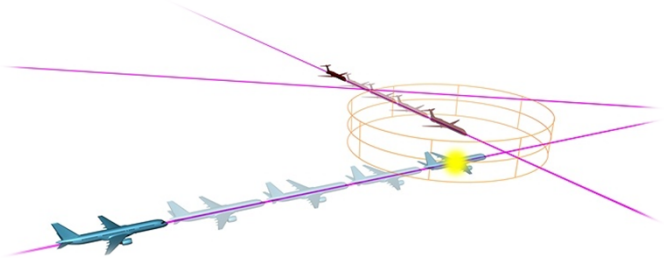
2012 2013 2014 2015 2016 2017 2018 2019

Early Adopter Application (TASAR)

Safety & Risk Assessments / Formal Methods

AFR Cost/Benefit (updated)

Automation Design Formalization and Minimum Performance Standards



Intent Broadcast Requirements

Degraded Modes & Recovery

Mixed Fleets

Reduced Separations

Mixed Ops Nominal Conditions

Mixed Ops Off-nominal Conditions

Advanced Weather Avoidance

Arrival / Dep. Procedures Integration

Full Mission & Crew Procedures

User Request Application Validation

AFR Validation Low Density Operations

AFR Validation High Density Operations

Analytical Research

Batch Experiments

HITL Experiments

Flight Testing

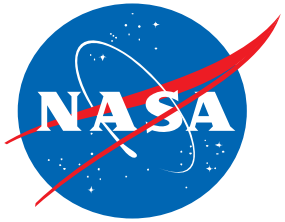
AFR Summary

- *Takes advantage of currently unused airspace capacity*
- *Designed to increase safety while dramatically reducing delay, excess flight miles, and flight trajectory inflexibility*
- *Overlays existing IFR and VFR with little or no impact to those operations*
- *Integrates unobtrusively alongside current and NextGen operations*
- *Offers a feasible transition path with immediate benefits*
- *Required technologies have finally emerged*

AFR introduction and detailed concept description:

Wing, D.J. and Cotton, W.B., "For Spacious Skies: Self-Separation with Autonomous Flight Rules in US Domestic Airspace," 11th AIAA Aviation Technology, Integration, and Operations Conference, AIAA-2011-6864, 2011.

Wing, D.J. and Cotton, W.B., Autonomous Flight Rules: A Concept for Self Separation in US Domestic Airspace, NASA/TP-2011-217174, 2011.

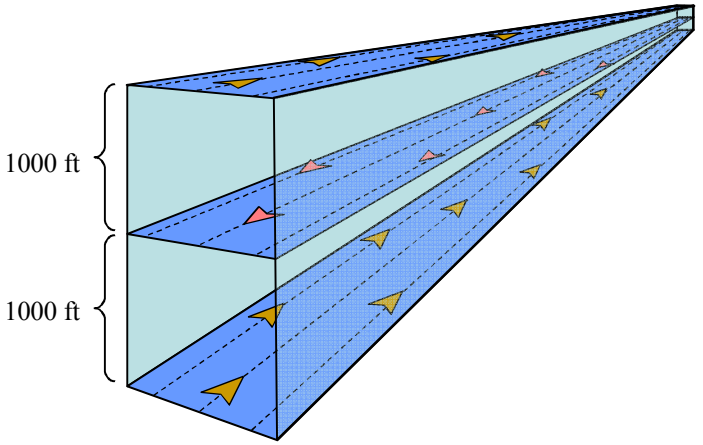

NASA

Backup slides

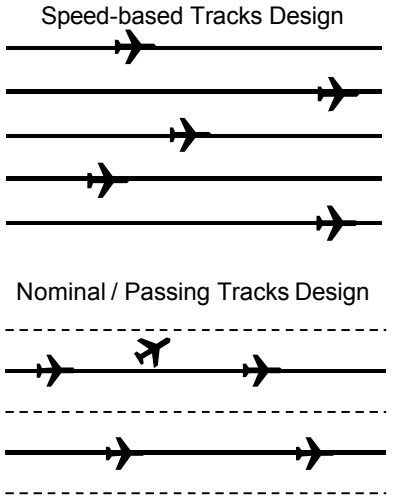
Self-Separation in Flow Corridors

2006 Dynamic Multi-track Airways Study

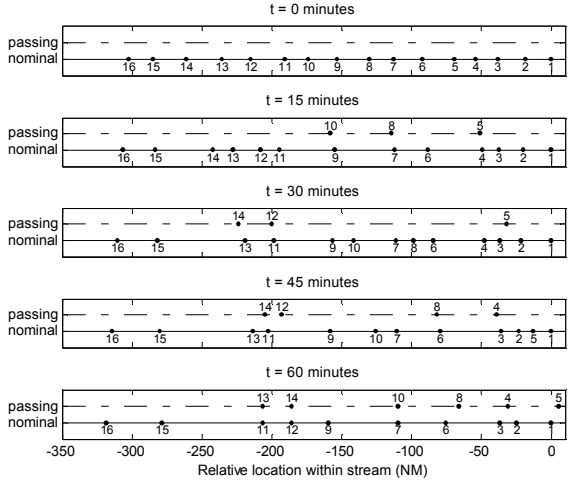
Issue	NextGen concept proposes self-separation in flow corridors; is the concept feasible and operationally beneficial?
Objective	Determine feasibility, potential benefits, and impact on flights and sector capacity
Approach	Develop concept and analytic models; analyze practical issues, design trade-offs, demand, capacity impacts; prototype the airborne automation
Key metrics	Sector loads, conflicts, delays, NAS demand
Results	Local sector congestion may be eased Full implementation serves 5-10% of NAS traffic Significant operational feasibility issues remain



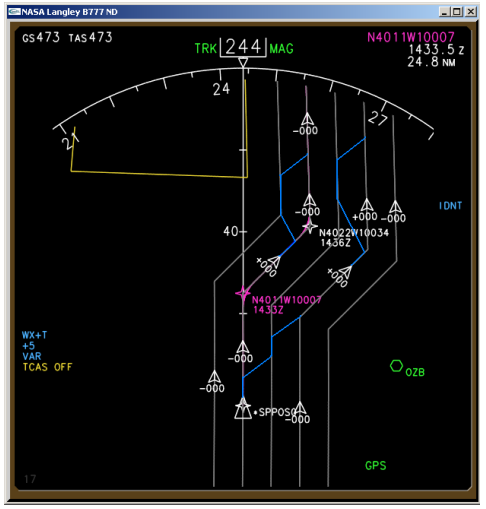
Multi-track Design Alternatives



Track Load Analysis



Prototype Passing Tool



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