AIRSPACE SYSTEMS PROGRAM

NEXTGEN

Pilot and Controller Evaluations of Separation Function Allocation in Air Traffic Management

10th USA/Europe Seminar on Air Traffic Management Research and Development
Chicago, IL, USA

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Technical Challenge and Objective

- Creating scalable system through “function allocation” of separation assurance
  – Eliminate human workload as a growth-limiting factor
  – Greater role for automation
  – Greater role for aircraft

- Paradigm shifts for ground and aircraft operations
  – Both approaches have significant implementation risk
  – Pursue both avenues and make compatible

- Motivation: 15+ years research on air and ground concepts for increasing capacity indicate powerful function allocation solutions
  – *Autonomous Flight Rules* (AFR)
    Distributed air/ground concept with self-separation-equipped operators
  – *Advanced Airspace Concept* (AAC)
    Trajectory-based concept with datacom-equipped IFR operators

- Objective: enable mixed operations (not segregation)
  – Open airspace for all is key for user benefits
  – Provides largest range of viable operations for aviation community

- Approach: coordinated human-in-the-loop air/ground experiments
  – Homogeneous operations (completed 2010)
  – **Mixed Operations**

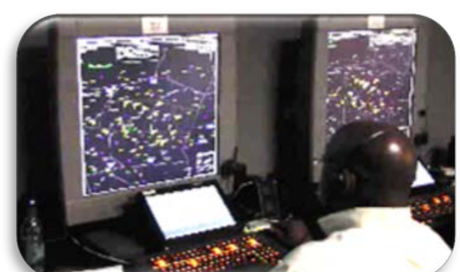
Aircraft

Human

Separation Functions
- Detect conflict
- Assign priority
- Strategic vs. tactical
- Compute resolution(s)
- Select maneuver
- Accept / execute
- Manage exceptions
- Meet constraints
- Etc.

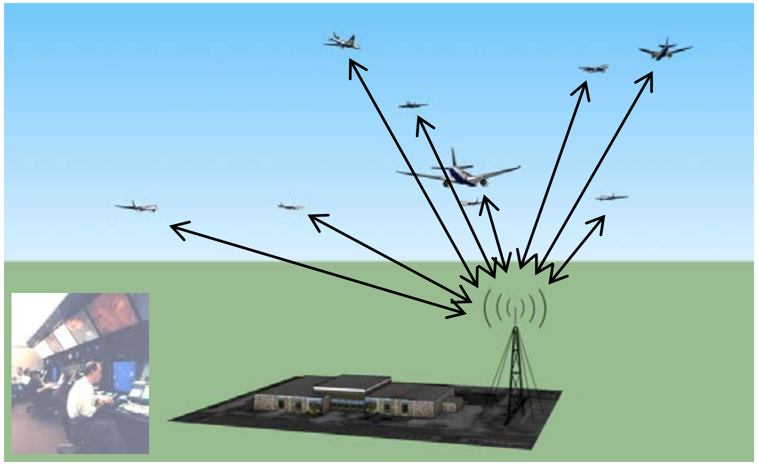
Automation

Ground



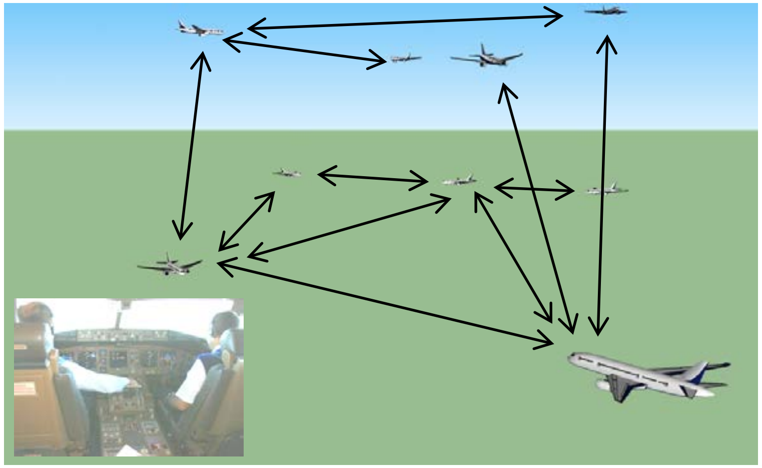
Separation Concepts

Ground-Based Automated Separation



- Automation increasingly used for primary separation
- Data link to send trajectory instructions to equipped aircraft
- Controller manages automation, airspace

Airborne Self-Separation

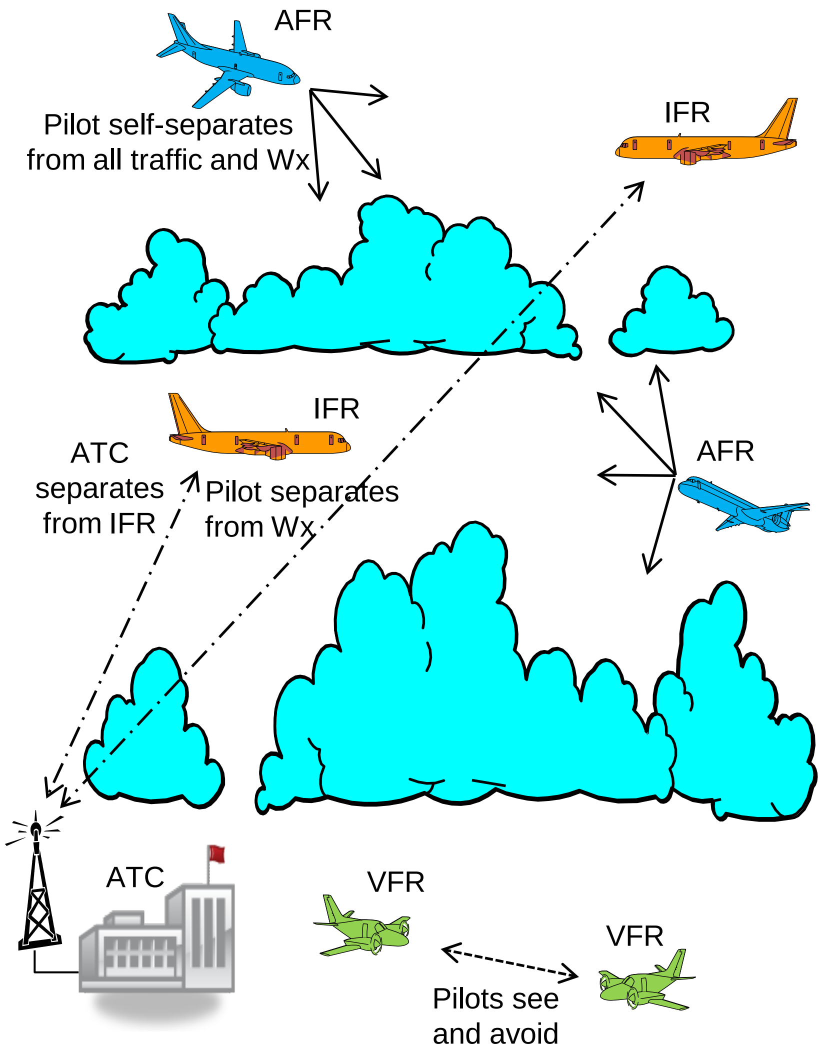


- Airborne surveillance
- Avionics-integrated automation for self-separation
- Pilot selects/executes maneuvers approved by automation

Mixed Operations

- Air Traffic Control (ATC) role
  - Separate IFR from IFR
  - Not responsible for AFR or AFR-IFR separation
  - Coordinate with AFR (voice) on IFR maneuvers near AFR

- AFR role
  - Separate from all traffic
  - Apply right-of-way with AFRs
  - Give right-of-way to <u>all</u> IFRs
  - Coordinate with ATC (voice) on short-notice conflict resolution maneuvers



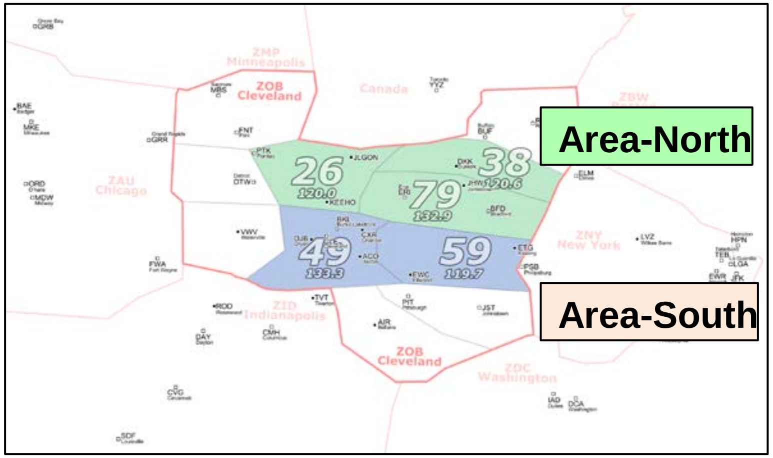
Key Research Issues for Mixed Operations

	Air/Ground	Human/Automation
Controller focused	**Effect of AFR on normal control of IFR traffic** **Test**: IFR only vs. mixed AFR-IFR traffic	**Compatibility with stages of NextGen evolution** **Test**: AFR-IFR traffic mix tested at four NextGen stages of IFR control
Pilot focused	**Flight deck ability to resolve all mixed (AFR-IFR) conflicts** **Test**: AFR-IFR conflicts with varying geometries and warning times	**Utility of intent information in mixed operations** **Test**: AFR-IFR operations with and without IFR intent information

These four issues were investigated in two coordinated Human-In-The-Loop experiments

Common Test Airspace and Configurations

- **Controller-focused experiment configuration**
  5 sectors, 2 areas, 2 ghost sectors
  8 single-pilot stations (AFR/IFR)
  8 pseudo-pilot stations (IFR)
  Subjects: 7 FAA front line managers

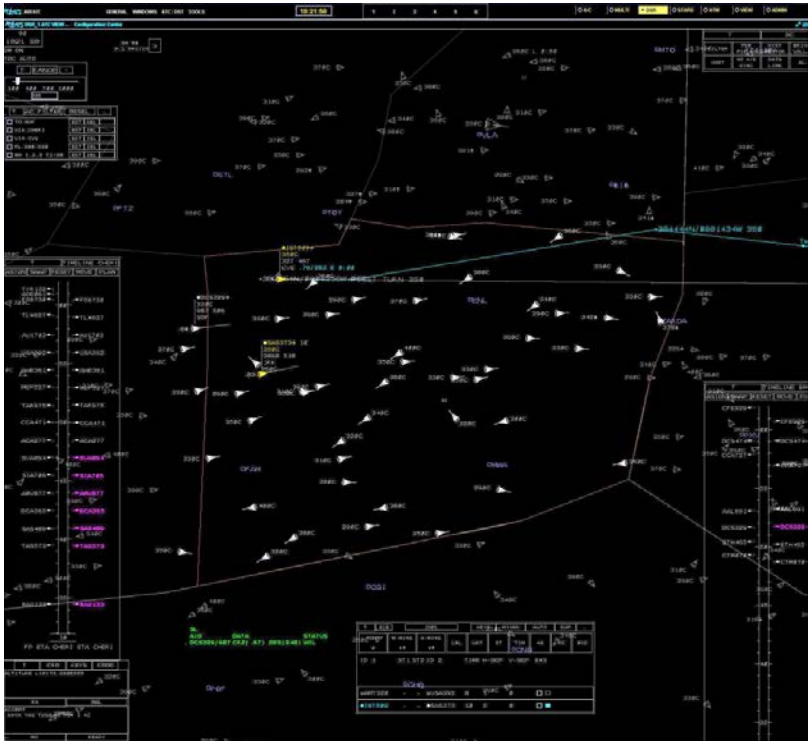


Cleveland Center (ZOB)
High altitude (FL 330 and above)

- **Pilot-focused experiment configuration**
  2 sectors (49, 59), 1 ghost sector
  6 “team” stations (AFR crew)
  3 pseudo pilot stations (IFR)
  Subjects: 17 airline flight crews

Separation Automation & Human Interface

Ground-Based Automation System



- Integrated display, functionality, & data link
- Automatic strategic & tactical conflict management
- Automated routine operations (handoffs, transfer of comm.)
- HMI designed for management by exception
- Accessibility to conflict info, resolution tools, trial plan tools, timelines
- Interactive via keyboard entry, data tags, trackball

MACS (Multi Aircraft Control Simulation)
High-fidelity display/control emulations for controllers, supervisors, pseudo-pilots

Separation Automation & Human Interface

Airborne Automation System

- Integrated with avionics
- Traffic separation in strategic and tactical flight modes
- Route optimization integrated with de-confliction
- Conformance with trajectory constraints
- Provisional probing for conflict-free trajectory changes
- Implicit coordination with traffic aircraft actions

ASTOR (Aircraft Simulation for Traffic Operations Research)
High-fidelity displays, controls, performance of modern Boeing-style jet

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Controller-Focused Experiment Matrix

		Tu, We	Th, Fr	Mo, Tu	We, Th
Air/ground function allocation	Mixed IFR/AFR				
	Ground IFR				
		Baseline	Minimum NextGen	Moderate NextGen	Maximum NextGen
		Human/automation function allocation NextGen Maturation Level of automation increases →			

NextGen Maturation

NextGen (NG) Level	Baseline	Minimum	Moderate	Maximum
Controller's role	IFR separation	IFR separation	IFR separation	Exceptions only (IFR)
Automation's role	Non-critical ATC support	Non-critical ATC support	Critical ATC support	IFR separation, critical ATC support
Automation capabilities	Conflict list	Conflict list	Plus trial planner; strategic resolver	Plus tactical resolver
IFR trajectory clearances	Voice	Voice	Voice / Datacom	Datacom
IFR frequency changes	Voice	Voice / Datacom	Voice / Datacom	Datacom
AFR frequency changes	Voice	Datacom	Datacom	Datacom
AFR access to IFR intent	No	No	Yes	Yes
ATC access to AFR intent	No	Yes	Yes	Yes
Traffic density	1x	1.2x	1.5x	2x
	Human/Automation function allocation NextGen Maturation Level of automation increases →			

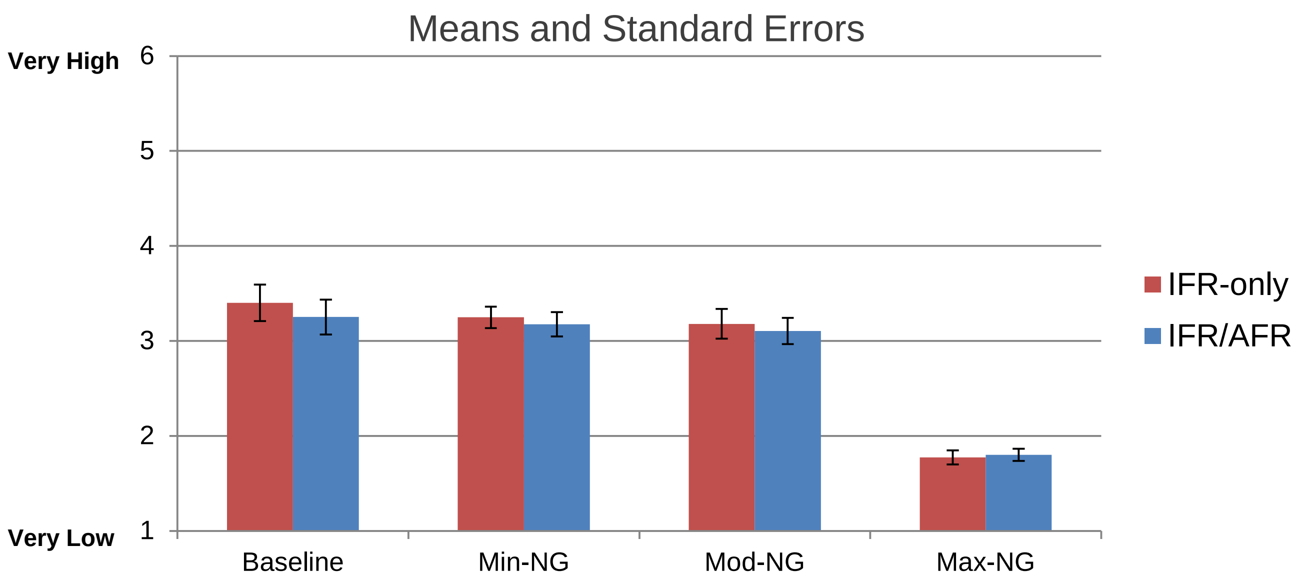
Loss of Separation (LOS) Events

	Traffic level	Monitor Alert Parameter	Data comm eq.	LOS IFR-only	LOS Mixed IFR/AFR all (AFR)
Baseline	1x	18	0%	1	1 (0)
Minimum	1.2x	22	25%	3	3 (2)
Moderate	1.5x	27	50%	10	5 (0)
Maximum	2.0x	36	100%	0	2 (0)

- Each data point represents 120 minutes of simulation time across five test sectors
- Half attributed to automation failures causing late conflict detections
- Half attributed to operator/automation interaction failures
- No statistically significant differences between IFR-only and Mixed IFR/AFR in each NextGen stage

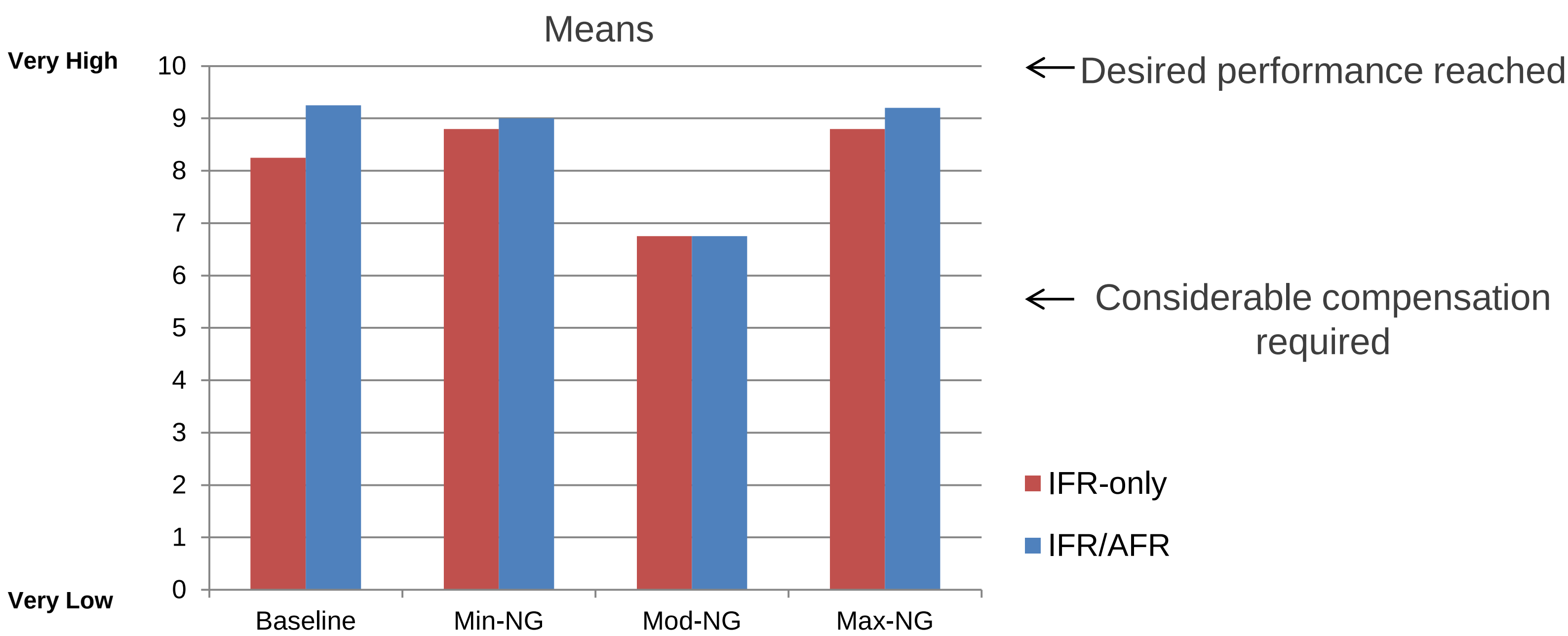
Loss of Separation: <5 nm lateral and <800 feet vertical

Controller Real-time Workload Ratings



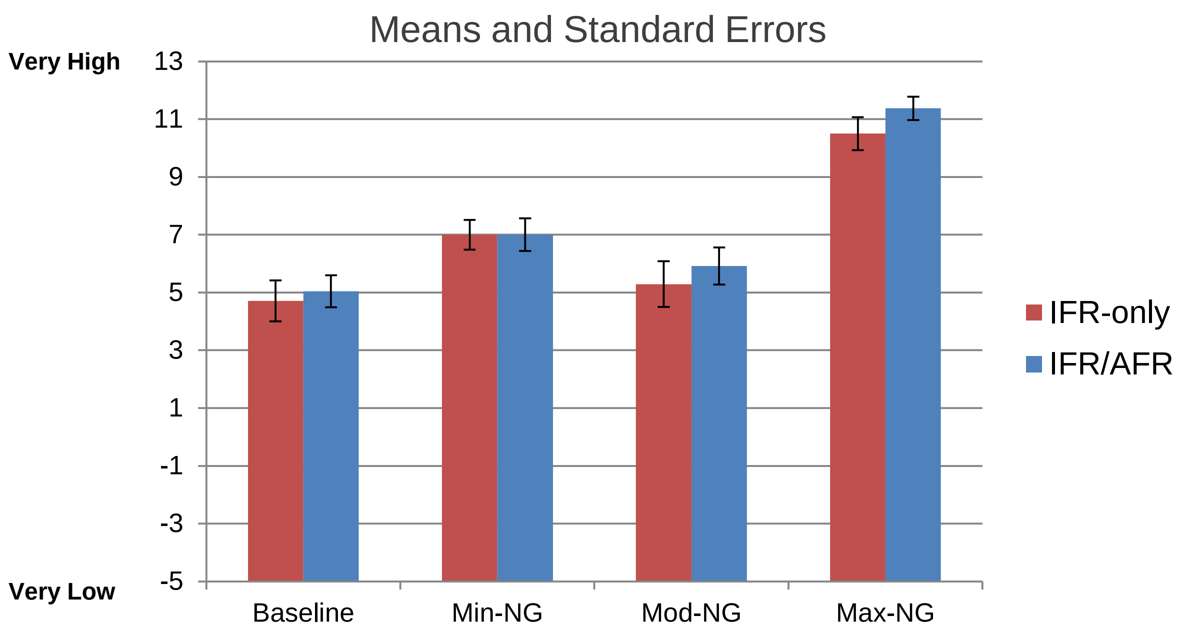
- Workload assessment tool, 6-point scale, gathered every 3 minutes
- No statistically significant differences between IFR-only and Mixed IFR/AFR
- Lowest workload in Maximum NextGen (“Max-NG”) condition

Controller Acceptability Ratings



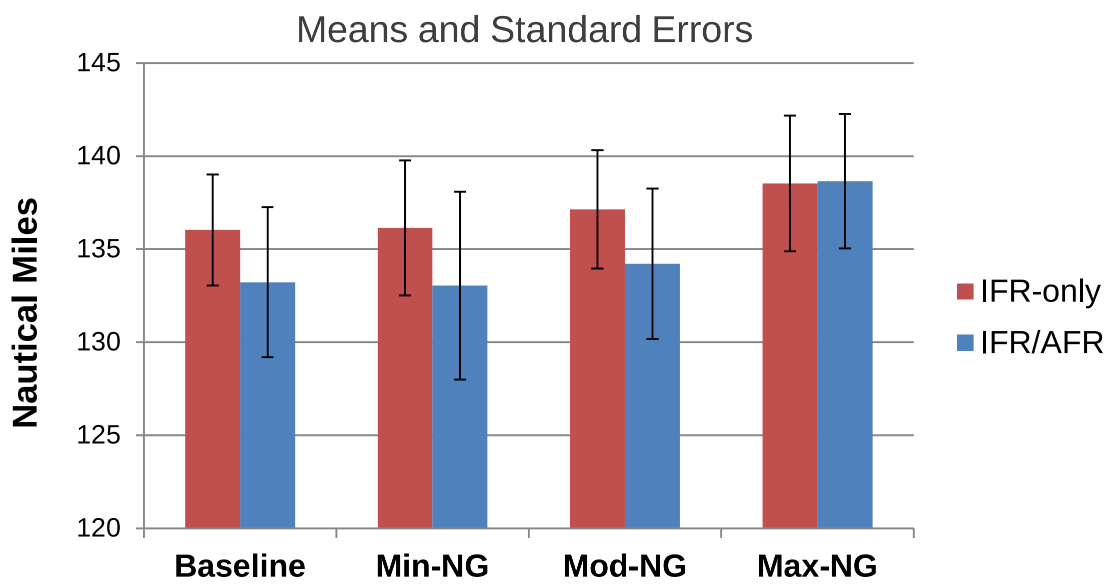
- Controller Acceptability Rating Scale (CARS), administered post-run
- Over all 8 conditions: 84% rated “acceptable”, 16% rated “less than acceptable”
- Some compensation required by controllers for smooth operations
- Mixed IFR/AFR operations rated same or slightly higher than IFR-only
- Lower mean rating in Moderate NextGen (“Mod-NG”) affected by late conflict detections

Controller Situation Awareness Ratings



- Situation Awareness Rating Tool (SART), administered post-run
- Highest situation awareness in Maximum NextGen ("Max-NG")
  - Perceived by controllers differently
  - Low demand, more spare capacity, higher understanding
- No statistically significant differences between IFR-only and IFR/AFR mixed operations

Progress Towards Destination



- Flight progress compared on similar routes after 20 minutes flight time
- More AFR maneuvering (less progress) expected to resolve AFR-IFR conflicts
  - IFR had 50/50 chance of being maneuvered for conflicts
- Baseline, Minimum NextGen (“Min-NG”), and Moderate NextGen (“Mod-NG”)
  - Less intent availability and/or reliability
- Maximum NextGen (“Max-NG”)
  - Similar efficiency when intent available

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Experiment Matrix: Part 1

Factors	Values				
Time to Buffer Loss	< 20 sec.	20-60 sec.	1-2 min.	2-4 min.	4-10 min.
Encounter Angle	Acute (0-50 deg.)			Obtuse (130-180 deg.)	
Maneuver Dimension	Lateral encounter			Vertical encounter	
Passage Orientation	Intruder passes in front			Intruder passes behind	

24 total conflicts tested, 10 minute runs,

Fractional [4]x[2x2x2] between-subjects design
(12 conflicts per crew)

LOS Events (AFR-IFR)

Initial Alert Time	Losses of Separation	Number of Runs
4 – 10 minutes	0	33
2 – 4 minutes	0	32
1 – 2 minutes	0	46
20-60 seconds †	11	62
< 20 seconds	0	15
Total	11	188

† Excludes 3 runs in this bin with borderline loss < 0.04 nmi

- 188 conflicts analyzed with varied initial alert time and conflict geometry (IFR intent not avail.)
- No LOS events for all runs with alert time > 60 seconds
- Pilot debrief comments: 5 or more minutes notice preferred
- No geometry effect evident (encounter angle, maneuver dimension, passage orientation)

Buffer Loss Events

Initial Alert Time	Buffer Losses ‡	Number of Runs
4 – 10 minutes	0	33
2 – 4 minutes	3	32
1 – 2 minutes	13	46
20-60 seconds	37	48
< 20 seconds	10	15
Total	63	174

- 3 nm safety buffer added to 5 nm lateral separation standard
  - Used by primary intent-based separation system
- Statistically significant difference between [2-10 minutes] and [1-2 minutes]
- Statistically significant effect of passage orientation
  - More effective in conflicts with intruder passing behind
- Statistically significant effect of encounter orientation
  - Suggests non-circular buffers more efficient

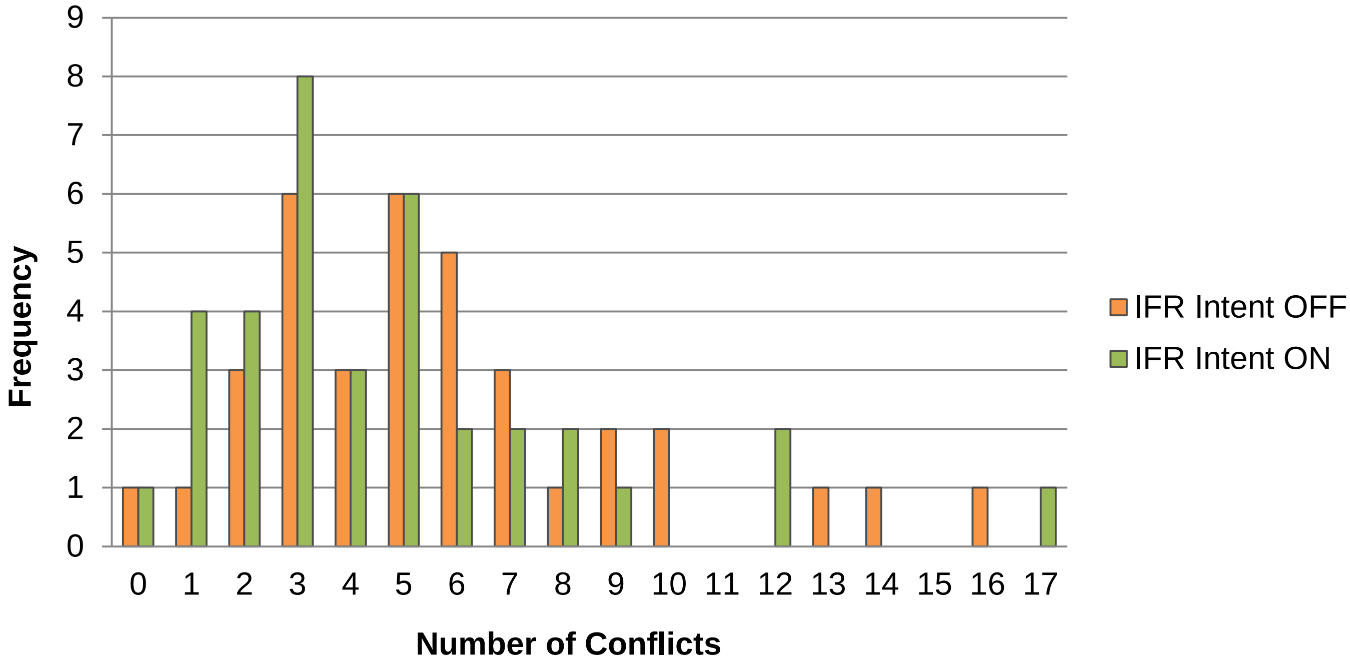
Experiment Matrix: Part 2

Factors	Values	
IFR Intent Availability	On	Off

30 minute runs, 72 total flights tested

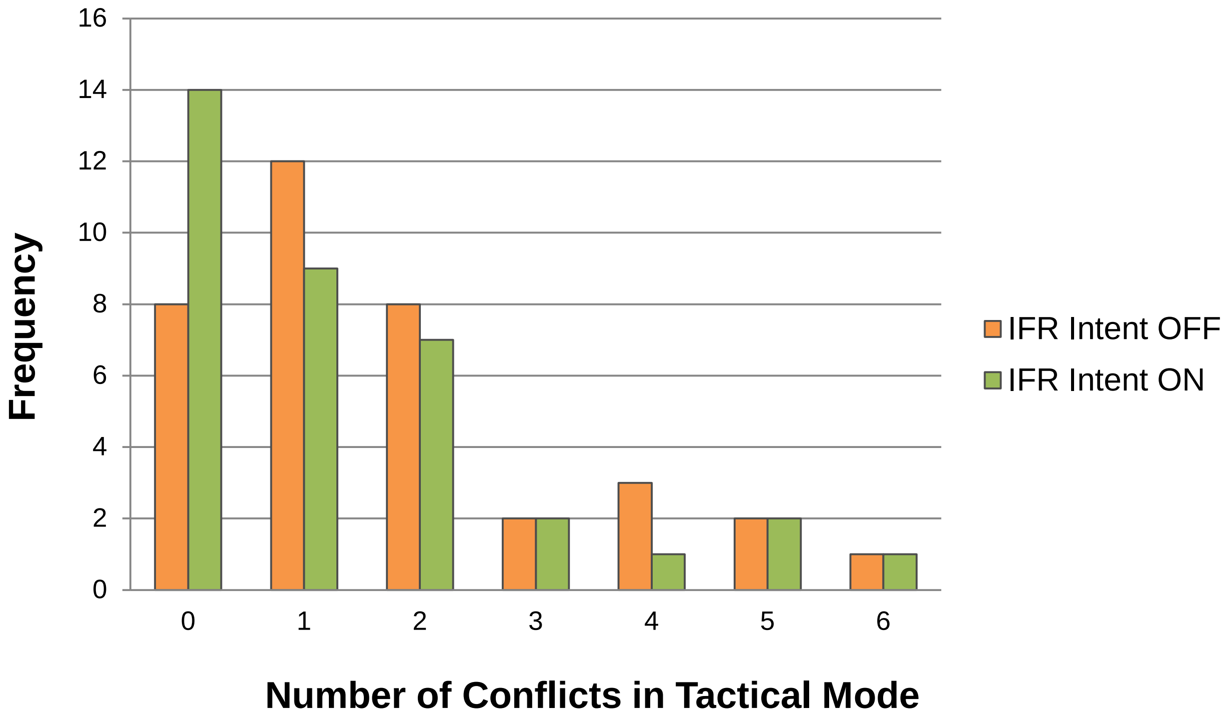
2x1 within-subjects design

Conflicts Per Flight



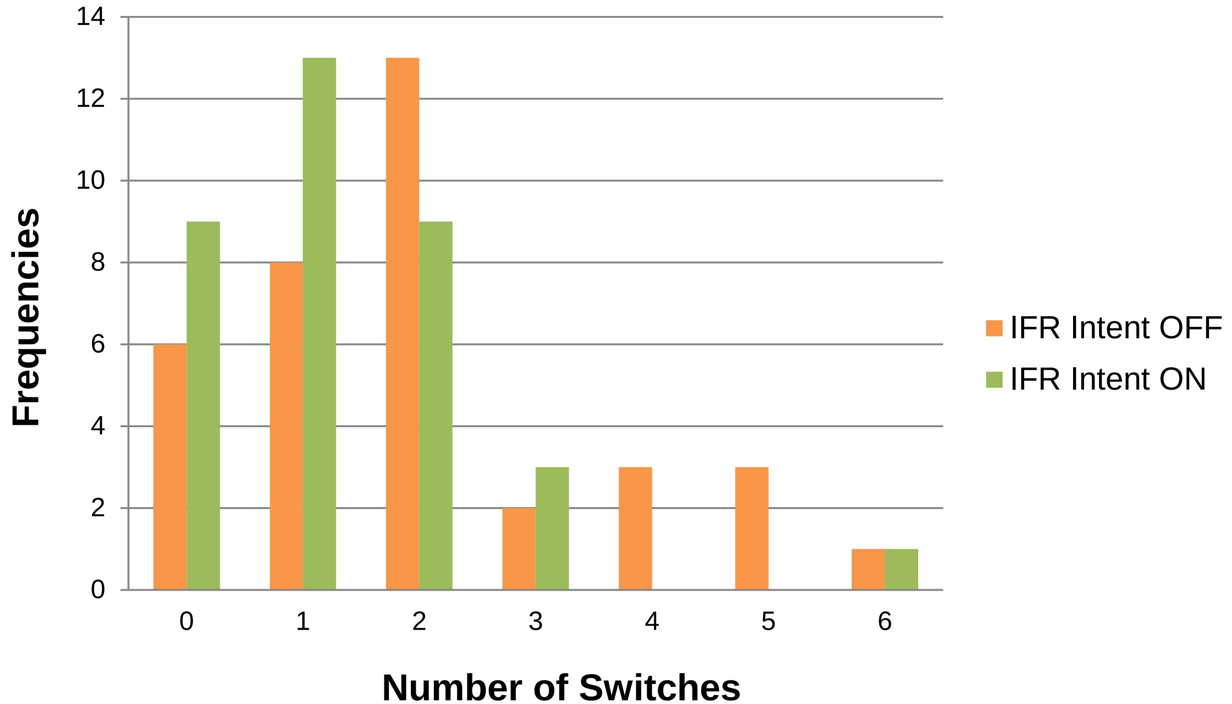
- 72 flights (30 min. each), 377 total conflicts detected, no LOS
- IFR Intent ON – 18% fewer conflicts, reduced tail (fewer cases of high conflicts/flight)
- Intent sharing promotes greater stability and efficiency of trajectories

Conflicts With Initial Alerting < 4 Min.



- 111 of 377 conflicts detected as “pop-ups” (<4 minutes notice)
- IFR Intent ON: 21% fewer pop-ups, reduced number of 1-conflict flights
- Pilot procedure for pop-up conflicts is to resolve with “tactical” rather than “strategic” solution

Switching Modes: Strategic to Tactical



- 122 auto-flight mode switches made (strategic to tactical)
- IFR Intent ON: 33% fewer mode switches
- Intent sharing promotes greater stability, efficiency, and predictability of trajectories

Conclusions

- No significant differences between these types of operations
  - Separation violations, controller workload, acceptability, and situation awareness
  - Presence of a few self-separating aircraft does not impact the performance of the ground-based separation system
- Flight crews reliably provided mixed-operations separation
  - In all cases where at least one minute warning was given
  - Preference was for at least five minutes notice
  - Regardless of encounter geometry
  - Key elements are sharing intent information and air/ground coordination on unplanned maneuvers
- Maximum NextGen stage outperformed all others
  - Same level of safety as the Baseline
  - Twice the throughput and a lot less controller workload
  - Equivalent maneuver delay, while all other stages required extra AFR maneuvering

Next Steps

Expanded Analysis of Function Allocation Concepts for Separation Assurance (SA)

- Document alternative concepts
- Seek community input, involvement
- Conduct various analyses and sims
- Summarize findings, recommendations