ATC Technologies for Controller-Managed and Autonomous Flight Operations

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Outline

- Introduction
- Air Traffic Control Tasks, Responsibilities, and Automation
- Design of the Ground-based Automation
  - Current day operations
  - Trajectory-based ATC
  - Mixed operations with airborne self-separation
- Ground Side Results
  - Trajectory-based ATC compared to current day
  - Mixed operations compared to trajectory-based ATC
- Concluding Remarks

Background

- The *Next Generation Air Transportation System (NGATS) Integrated Plan* requires
"… research to evaluate alternative allocations of air traffic management services and functions between the ground and the air, and the automation and the human, to address critical system attributes such as capacity, agility, cost, human factors, reliability, safety, performance, and transition paths."

- *Distributed Air/Ground Traffic Management (DAG-TM)* research investigated concepts like airborne self-separation, airborne spacing and trajectory negotiation
  - *Trajectory negotiation*
    - Integration of ground-based DSTs and airborne trajectory planning tools via data link
    - No change in separation responsibility
    - Improve efficiency and accommodate user preferences by communicating 4D trajectories more effectively
  - *En route free maneuvering*
    - Mixed operations with airborne self-separation
    - Delegates the responsibility for separation assurance to the flight crews of properly equipped aircraft
    - Increase capacity and accommodate user preferences by letting flight crews fly their preferred routes

Design of the ground based automation

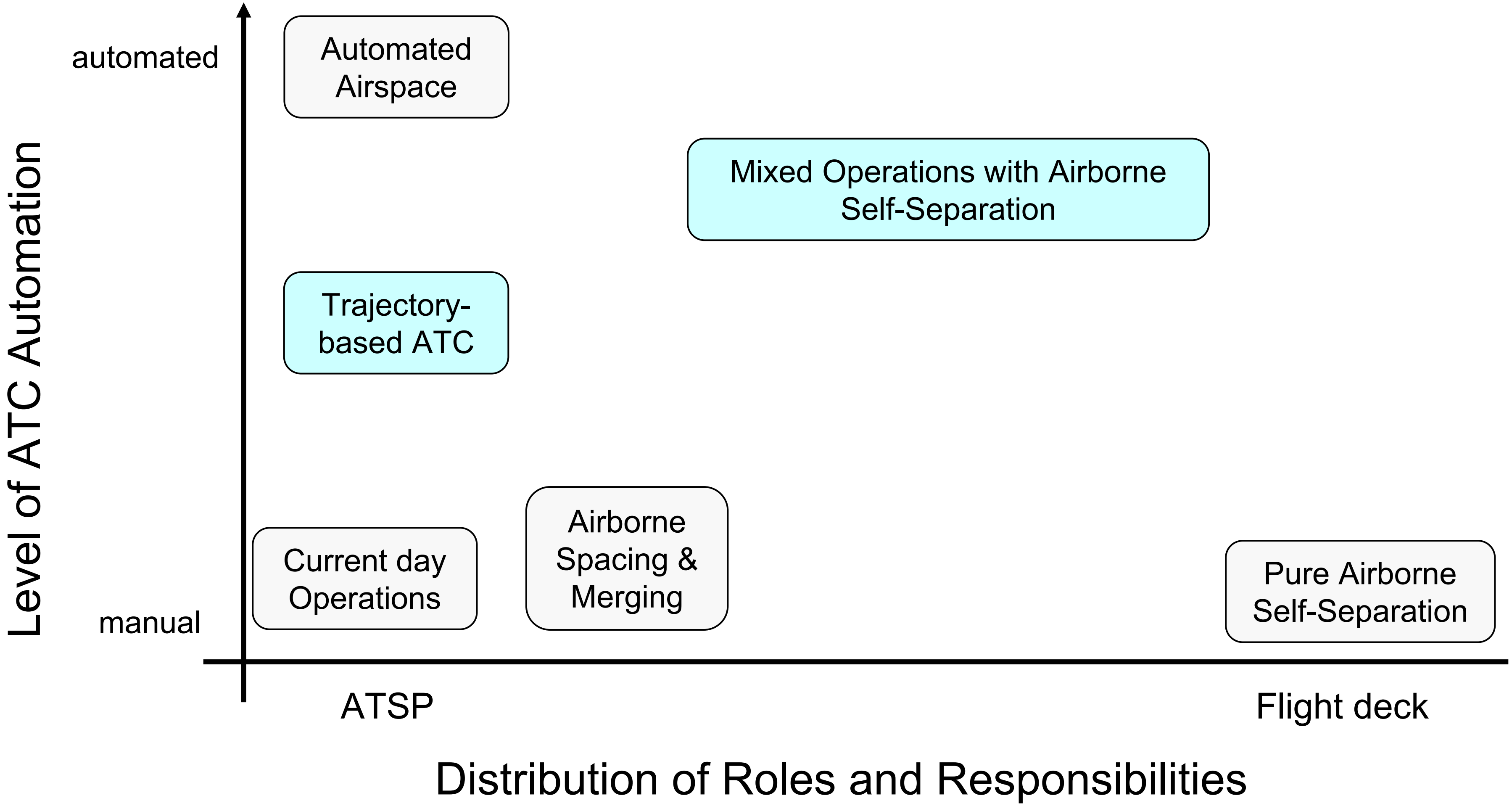
- Design is driven by
  - Air traffic control tasks to be accomplished
  - Distribution of roles and responsibilities (as defined by the operational concept
  - Level of automation (derived from the controller/automation interaction philospphy)

Air traffic control tasks

- FAA order 7110.65 states:
  - "*The primary purpose of the ATC system is to prevent a collision between aircraft operating in the system and to organize and expedite the flow of traffic. In addition to its primary function, the ATC system has the capability to provide (with certain limitations) additional services*."

- Task breakdown:
  - Separation assurance
    - Short and medium term conflict detection and resolution
  - Traffic flow management
    - Spacing, scheduling, and metering
  - Additional services
    - Accommodate user preferences
  - Routine and bookkeeping
    - Transfer of control and communication, data entries (e.g. flight plan amendments, altitude assignments, etc.)

Operational concepts and level of automation



Current air traffic control system

Primary task	Sub tasks	Controller	R-Side Automation support	D-Side/TMU Automation support	Flight crew
Separation assurance	Short-term conflict detection	monitor traffic within the sector for potential LOS	Conflict Alert (< 2 minutes to LOS) J-Ring, Predictor		-
	Tactical conflict avoidance	Vectoring/voice	-	-	Execute maneuver
	Medium- term conflict detection	Monitor traffic within the sector	-	Flight plan based probe (URET) in some facilities	-
	Strategic conflict resolution	judgment, Clearance amendment or vectoring/voice	-	-	Program new flight path
	Strategic conflict prevention	Airspace design, standard routings and flight rules,	-	-	Follow flight rules
Traffic flow management	Spacing	Vectoring/voice	Range rings		
	Scheduling	Miles in trail or STAs	-	CTAS Traffic Management Advisor	-
	Metering	Vectoring/voice	Meter list		
Additional services	Accommodating user preferences	Judgment, Manual assessment Clearance amendment or vectoring/voice	-	-	Requests/voice
Routine and bookkeeping tasks	Transfer of control	manual	Auto handoff, if aircraft is en route		-
	Transfer of communication	Manual/voice	-	-	Initial contact with next sector
	Data entries	manual	-	-	

Trajectory-based ATC

- Goal: Efficiency and capacity improvements without changing roles and responsibilities
- Free up controller resources by introducing automation integrated into controller workstation
- Integrated air/ground system infrastructure provides reliable trajectory predictions for all aircraft and framework for efficiently exchanging trajectories
- Relieve controllers of many of the routine tasks
- Provide reliable and responsive trajectory planning tools

Ames Research Center

Example controller display

Trajectory-based ATC

task	Sub tasks	Controller	R-Side Automation support
Separation assurance	**Short-term conflict detection**	monitor traffic within the sector for potential LOS	Improved Conflict Alert (< 2 minutes to LOS), Commanded trajectory based Conflict probe (1-5 minutes) J-Ring, Predictor
	Tactical conflict avoidance	Vectoring/voice	-
	Medium- term conflict detection	Monitor traffic and conflict feedback	Planned trajectory based Conflict probe (4-30 min)
	Strategic conflict resolution	Trial plan and data link route/altitude	Trial planner with responsive conflict feedback integrated with data link
	Strategic conflict prevention	Strategic conflict detection and flight rules,	Conflict probe
Traffic flow management	**Spacing**	Vectoring/voice	Range rings
	Scheduling	STAs	Timeline with scheduling functions
	Metering	Uplink provided speed advisories, trial plan delay trajectory, data link route and/or cruise altitude changes	Timeline, Delay feedback Speed advisory and trial planner integrated with data link
Additional services	**Accommodating user preferences**	Conflict probe of downlinked trajectory and data link response	Trial planning/conflict probing
Routine and bookkeeping tasks	**Transfer of control**	Manual/Automatic as desired	Auto handoff for all aircraft along trajectory
	Transfer of communication	Manual/Automatic as desired	Automatic or manual release via data link
	Data entries	Manual/ Automatic upon accepting or sending if trial planned or advisory	One click data link host amendment from trial planner

Mixed operations with airborne self-separation

- Goal: Efficiency and capacity improvements by assigning responsibilities for separation to flight crews of properly equipped aircraft
- Minimize impact of “autonomous aircraft” on controller workload
- Flight crews of “autonomous” aircraft separate themselves from all other traffic
- “Autonomous Flight Rules” defined
- Integrated air/ground system infrastructure provides reliable trajectory predictions for all aircraft and framework for efficiently exchanging trajectories
- Trajectory-based ATC environment necessary
- Automation conducts all routine tasks for AFR aircraft

Mixed operations with airborne self-separation

Primary task	Sub tasks	Controller	R-Side Automation support	Flight crew
Separation assurance	Short-term conflict detection	monitor traffic within the sector for potential LOS	Improved Conflict Alert (< 2 minutes to LOS), Commanded trajectory based Conflict probe (1-5 minutes) J-Ring, Predictor	Flight deck automation and monitoring
	Tactical conflict avoidance	Contact flight crew	-	Avoid conflict
	Medium- term conflict detection	-	-	-
	Strategic conflict resolution	-	-	Automation assisted flight path change
	Strategic conflict prevention	-	-	Follow flight rules
Traffic flow manageme nt	Spacing	-	-	
	Scheduling	STAs	Timeline with scheduling functions	
	Metering	Gatekeeper function	Automatic uplink of RTA	RTA compliance
Additional services	Accommodating user preferences	-	Process downlinked trajectories	Can select their flight path freely
Routine and bookkeepin g tasks	Transfer of control	-	Auto handoff for all aircraft along trajectory	-
	Transfer of communication	-	Automatic via data link	Initial contact with next sector
	Data entries		Automatic from downlinked data	

OVERFLIGHT DATA BLOCKS (GREEN)

Full IFR Overflight

```
CPDLC symbol → ◆USA678→ 13
(explained in section 3.x)  330C
                            146 484
                              |
filled ♦ indicates track control → ♦
```

Expanded IFR Overflight

```
◆USA678→ 13
330C
146 484
current airspeed or mach (ADS-B)→ 280
  |
  ♦
```

Limited IFR Overflight

```
  330
unfilled ◊ indicates *no* track control → ◊
```

Full AFR Overflight

```
◆TWA952
330C
146 484
  |
  ♦
```

Expanded AF R Overflight

```
◆TWA952
330C
146 484
  280
  |
  ♦
```

Limited AFR Overflight

```
◊329↓
altitude status (level, climbing, descending)↗
```

ARRIVAL DATA BLOCKS (TAN)

Full IFR Arrival

```
◆DAL510→ ← route trial plan "portal"
330C
146 484
.72/266 ← STA "meet-time" speed advisory
  |
  ♦
```

```
◆DAL510→ 4
330C
146 484
  E 0:12 ← trial plan ETA-STA difference (m:ss)
  |
  ♦
```

Expanded IFR Arrival

```
◆DAL510→ 4 ← color coded time to (earliest) conflict
330C          red  tc <= 2 min
146 484       yellow 2 min < tc <=5 min
.72/266 280   white tc > 5 min
  |           magenta conflict with AFR a/c
  ♦
01:41:09 ←STA
  (expanded data block)
```

Full AFR Arrival

```
◆UAL10 2
330C
146 484
E 0:12(R)← ETA-RTA error (m:ss)
  |
  ♦
```

Expanded AFR Arrival

```
◆UAL10 USA678 ← color-coded confict a/c ID
330C            (expanded data blocks)
146 484
E 0:12(R) 280
  |
  ♦
01:41:09
```

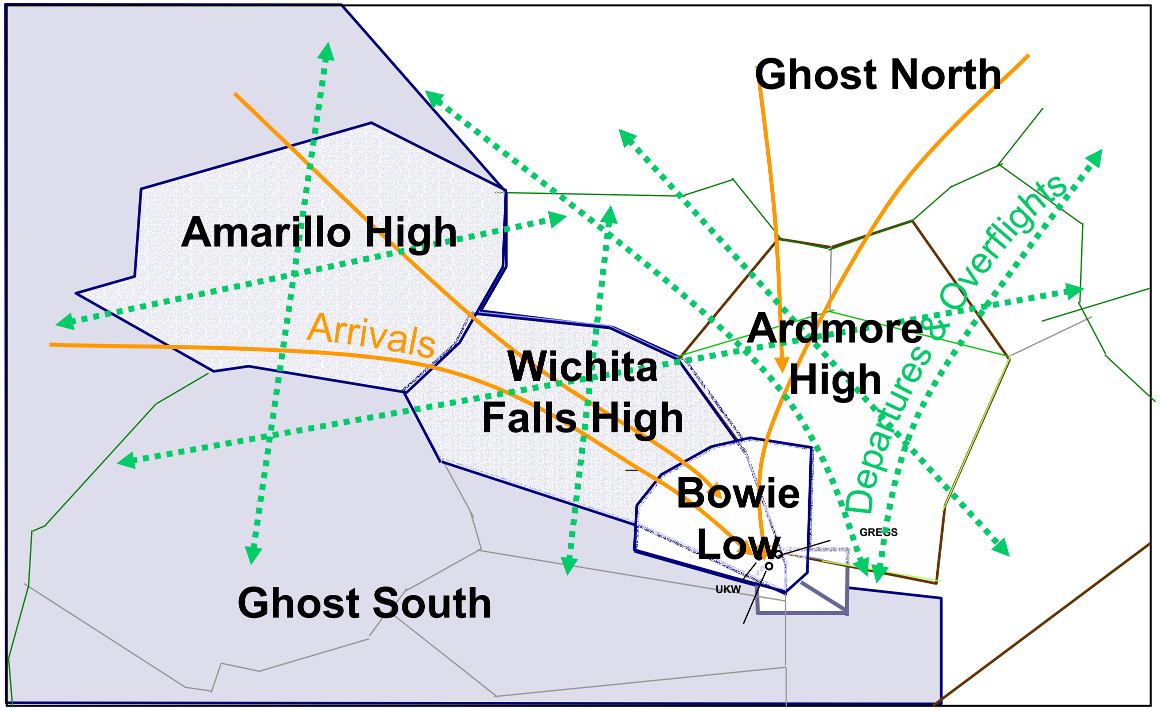
Limited AFR Arrival

```
◆330C® ↖ RTA assigned
```

Simulation Evaluation

- Simulations at NASA Ames in
  - 2002 (trajectory-based ATC and mixed ops)
  - 2003 (trajectory negotiation)

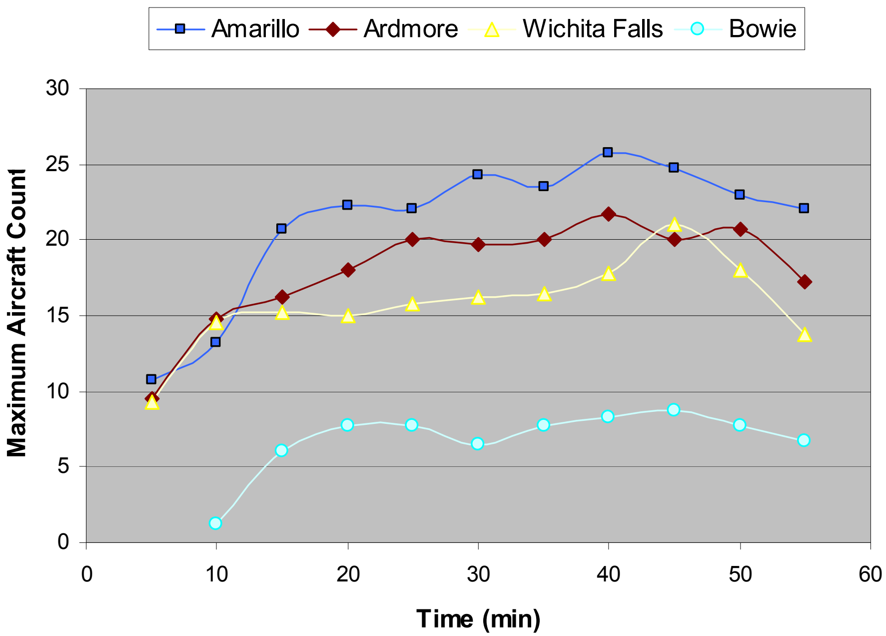
- Joint Ames/ Langley simulation in 2004 to evaluate mixed operations and scalability



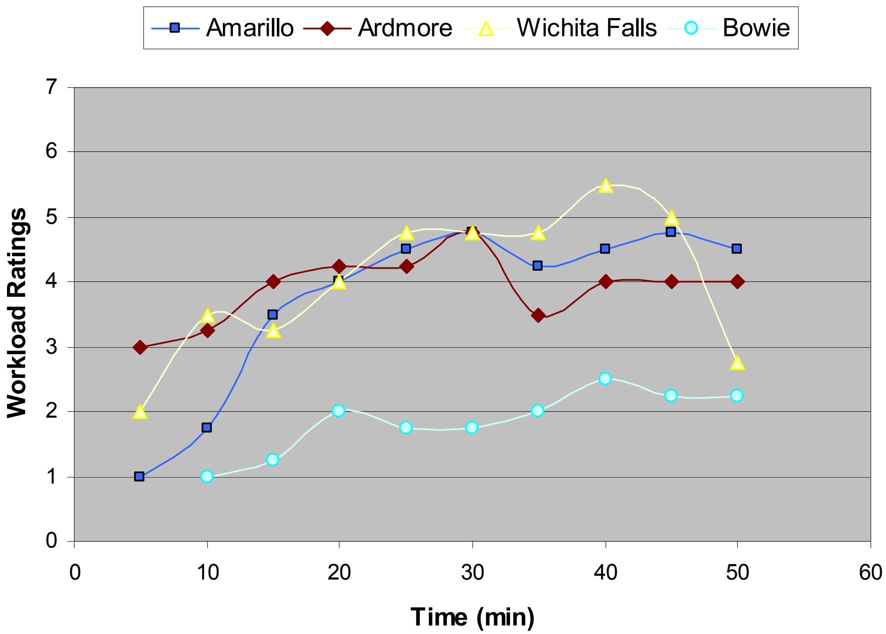
- All simulations used the same airspace with 4+1 certified professional controllers and up to 22 pilot participants

Trajectory-based ATC: Traffic load and workload

- Up to 150 % of current day traffic volumes were handled by one controller per position, causing moderately high workload



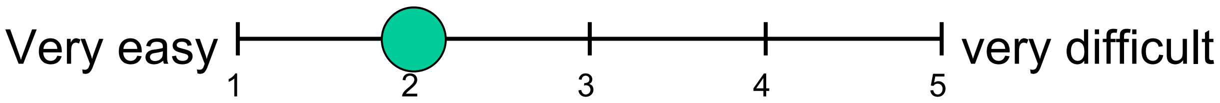
Number of controlled aircraft averaged in 5 minute increments



Controller workload

Trajectory-based ATC: Safety

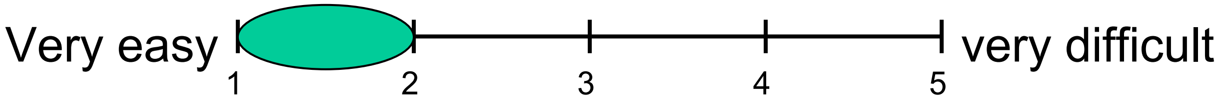
How difficult was it to monitor and maintain separation?



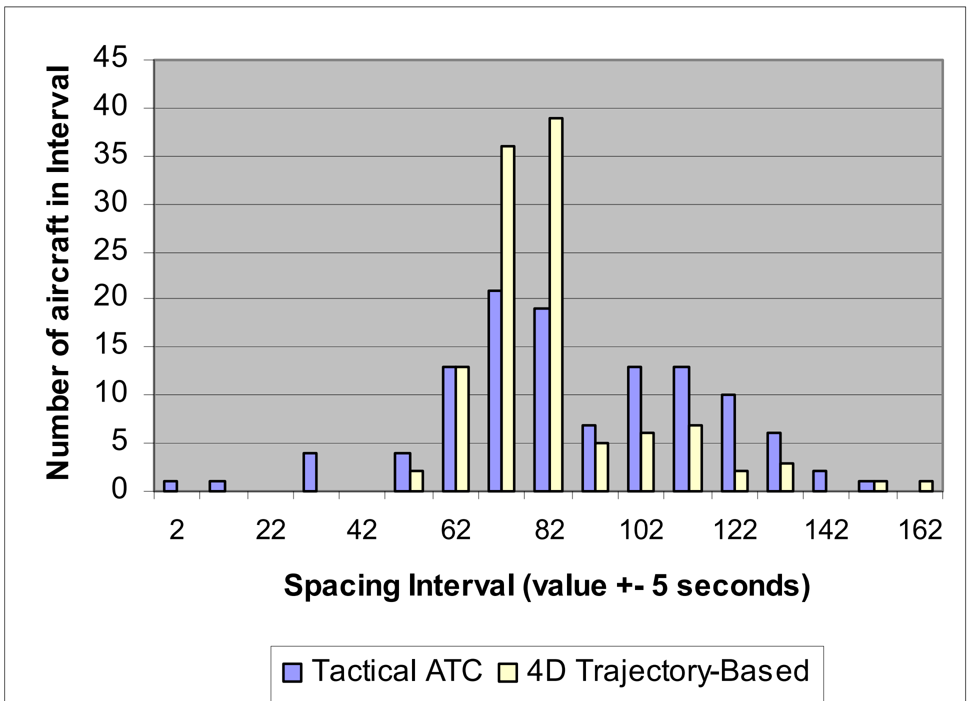
- All controllers rated it easy (2) to monitor separation
- No indication that trajectory-based ATC has negative safety impacts
- Controllers used tools to avoid conflicts strategically
- All current day safety measures still apply

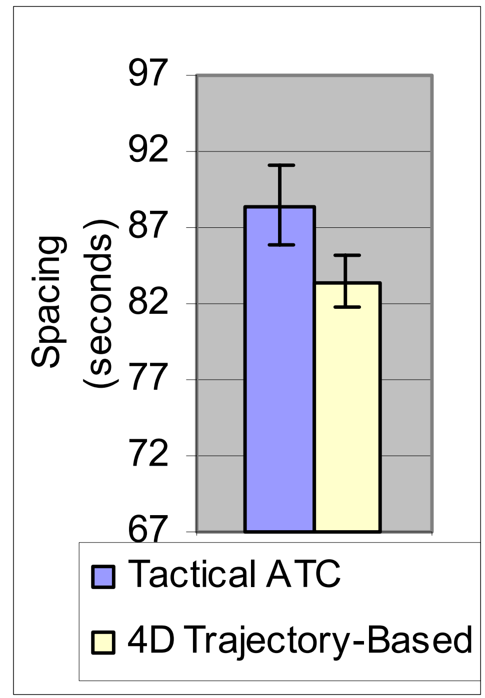
Trajectory-based ATC: Metering

How difficult was it to deliver aircraft on schedule?

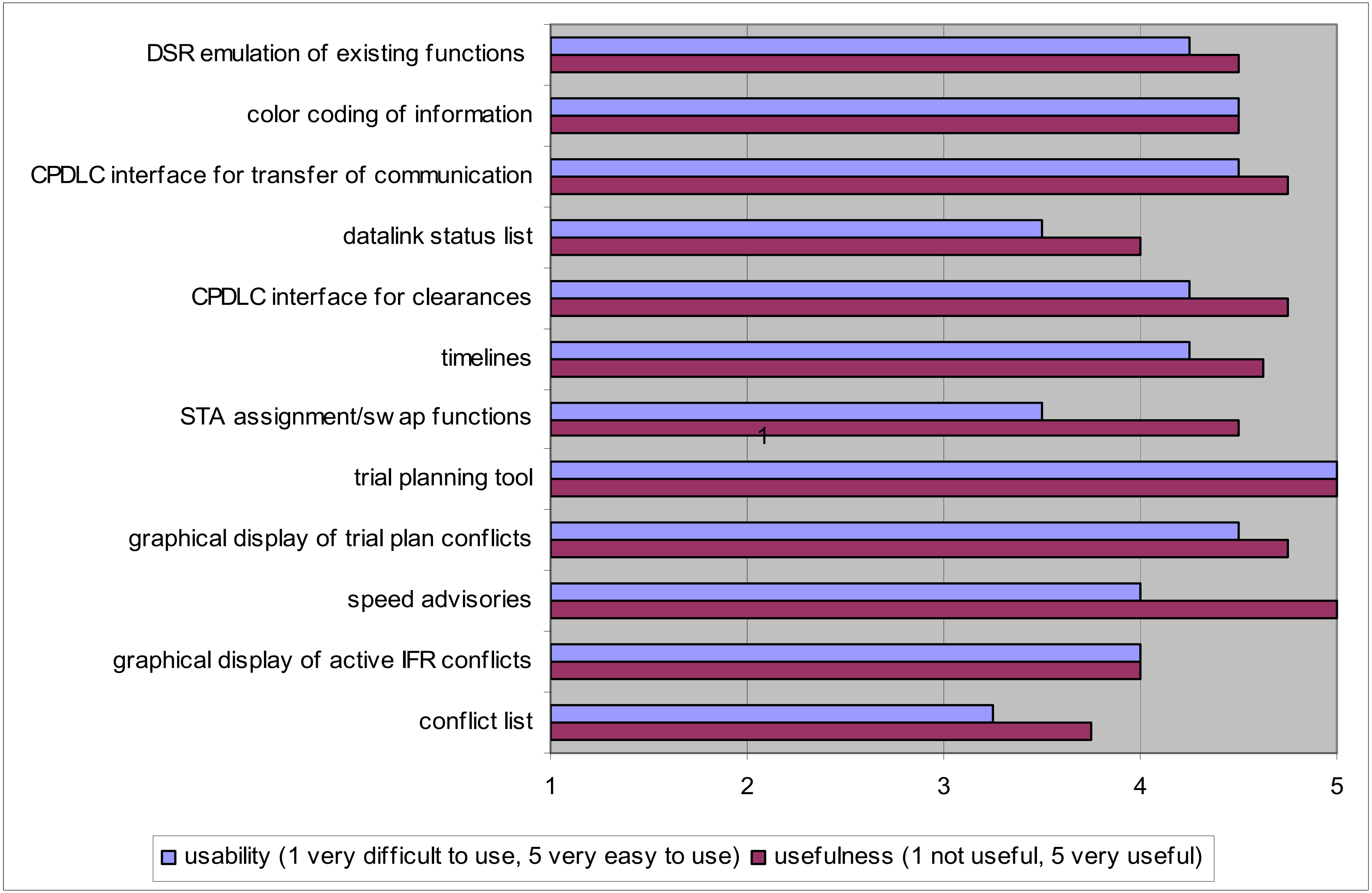


- Half of the controllers rated it very easy (1), half easy (2) to deliver aircraft on schedule
- This confirms results of simulations in 2002 that showed a significant increase in delivery accuracy





Trajectory-based ATC: Tool usability and usefulness

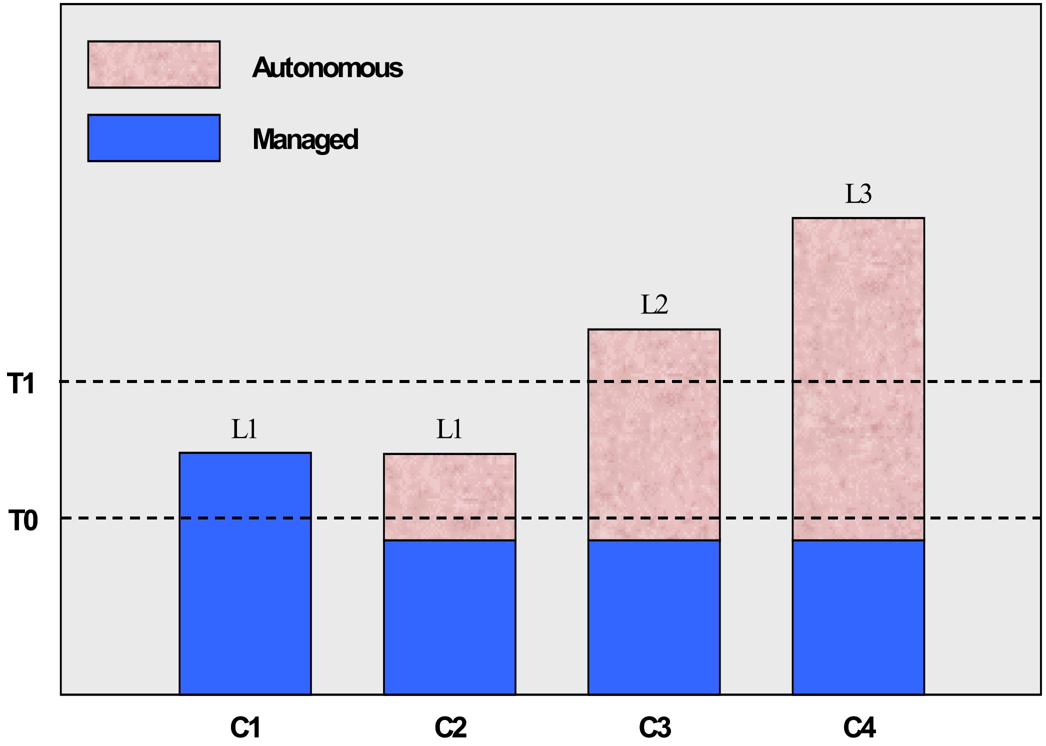


Trajectory-based ATC: Controller Feedback

Question	Range	Low Altitude controller	High Altitude controller #1	High Altitude controller #2	En route controlle r		Avera ge
How useful was the ability to obtain speed advisories when trying to deliver aircraft to a meter fix STA?	extremely useful (5) not very useful (1)	**5**	**5**	**5**	N/A		**5**
What impact do you think the ability to datalink clearances had on your overall workload?	greatly reduced (5) greatly increased (1)	**5**	**5**	**4**	N/A		**4.67**
How effective were cruise and descent speed clearances for controlling arrival traffic compared to current operations?	much more effective (5) much less effective (1)	**4**	**5**	**4.5**	N/A		**4.5**
How effective were trial plan route amendments compared to vectoring used in current day operations?	much more effective (5) much less effective (1)	**5**	**5**	**5**	**4**		**4.75**
How effective were trial plan altitude amendments compared to current day operations?	much more effective (5) much less effective (1)	**3**	**5**	**5**	**4**		**4.25**
How useful was the ability to datalink clearances compared to voice clearances?	much more useful (5) much less useful (1)	**5**	**5**	**5**	**5**		**5**

Mixed Operations: Experimental Design

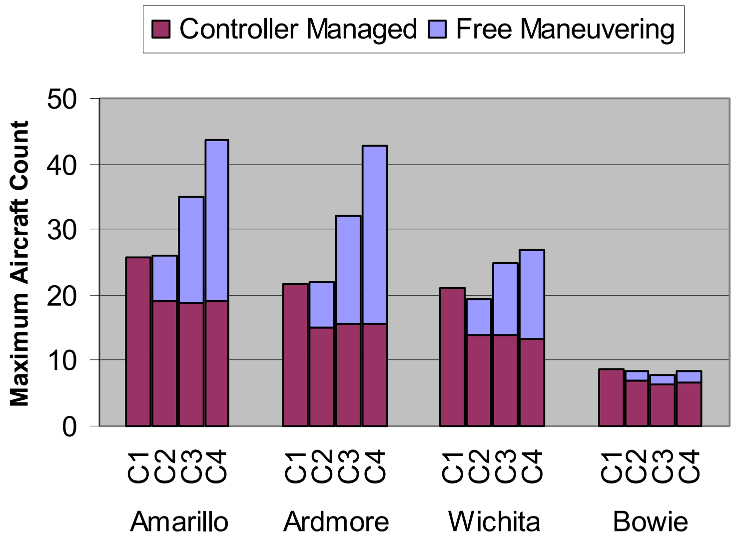
- Investigate two primary issues:
  - Feasibility of mixed operations
  - Scalability of en route capacity

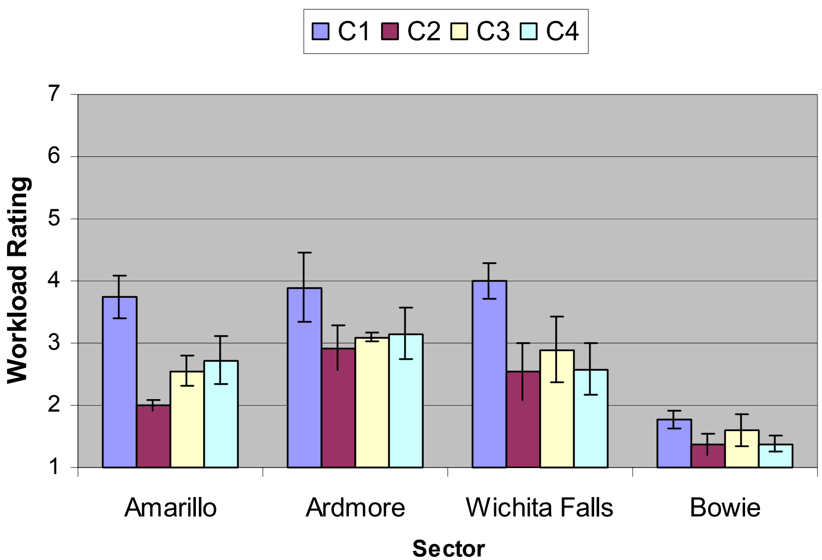


- Condition 1: trajectory-based ATC condition explained before
- Condition 2 replaced 30% of managed aircraft with autonomous aircraft
- Conditions 3 and 4 increased number of autonomous aircraft, with constant number of managed aircraft

Mixed Operations: Traffic load and workload

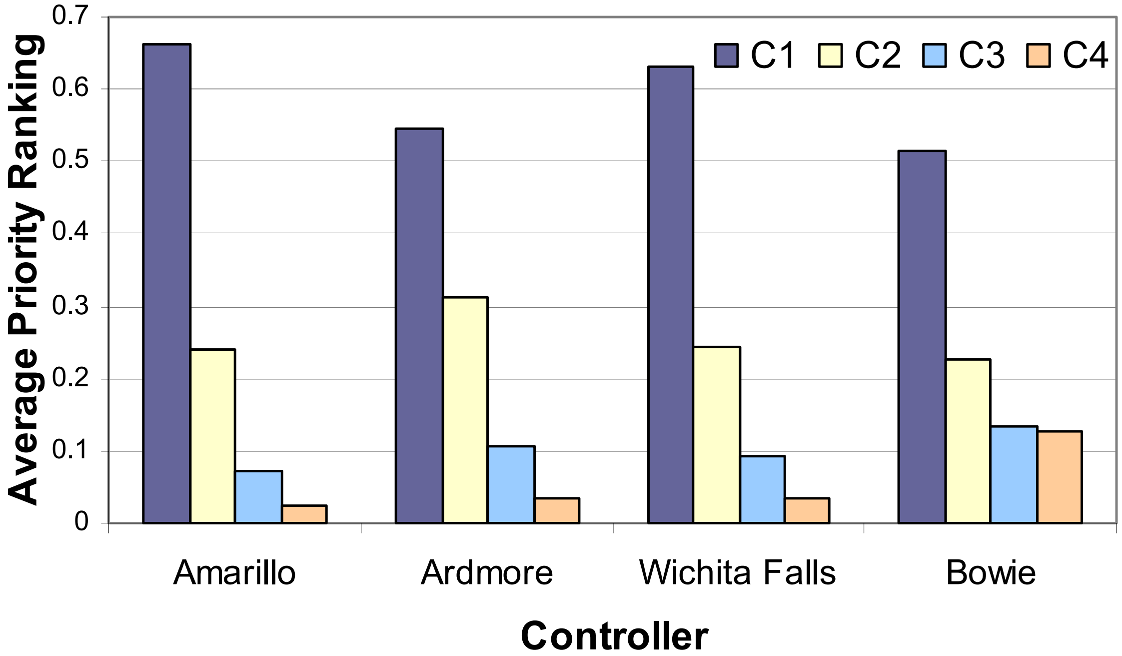
- Traffic loads in some sectors exceeded current day values by far (up to 2.5 x)
- Controller workload appeared to be correlated primarily to the number of IFR aircraft in the airspace
- AFR aircraft had little impact on controller workload, but increased complexity



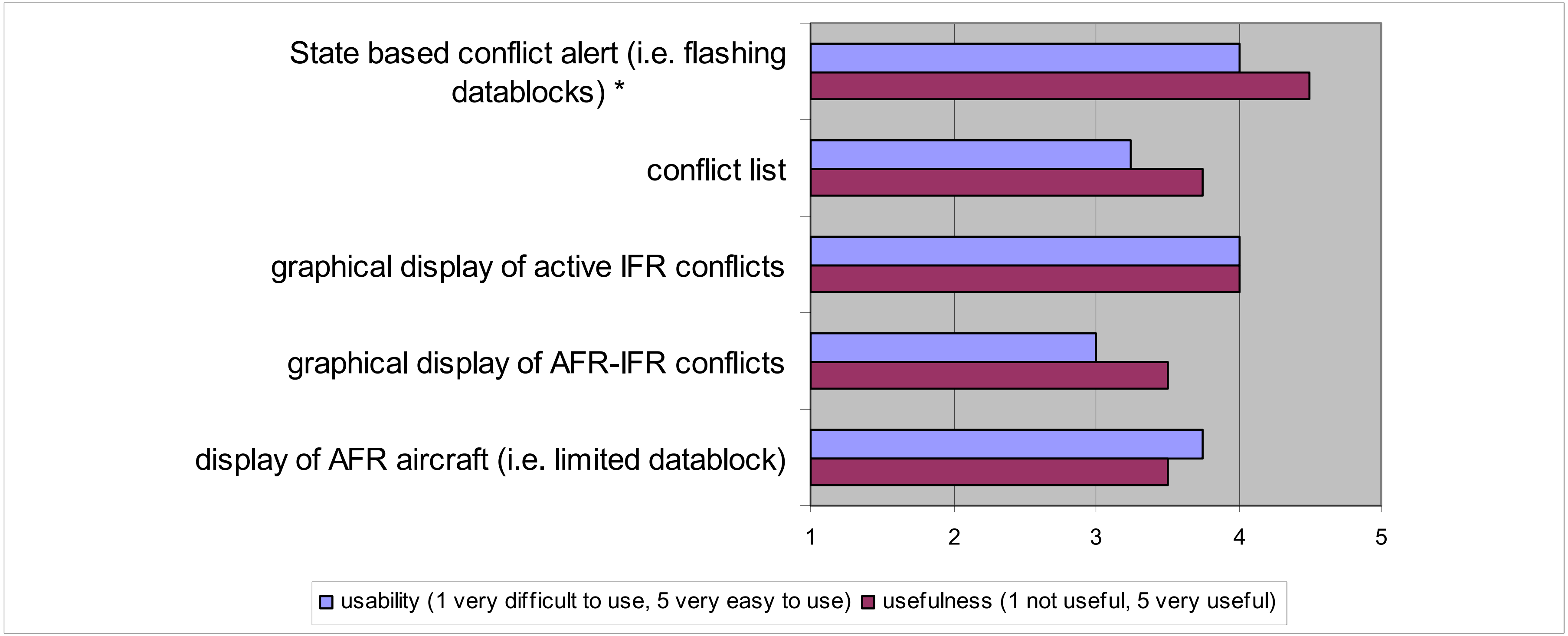


Mixed Operations: Safety

- Controllers rated mixed operations less safe than all managed operations (Barhydt & Kopardekar, ATM 2005)



- Most safety concerns were related to IFR/AFR interactions
- Short-term conflicts and separation violations often due to software crashes and non-participating aircraft
- Concept refinements and more research required to address safety issues



- Display of IFR/AFR conflicts and display of AFR aircraft with limited data tags was rated only somewhat useful and usable
- Routine and bookkeeping tasks were handled efficiently by the automation and contributed to workload reduction

Mixed Operations: Controller Acceptance

- Mixed operations were rated slightly more efficient than all-managed ops

  (M = 3.5; 1 = much less efficient, 5 = much more efficient)
- Somewhat negative impression on situation awareness and safety

  (M = 2.25; 1 = much less safe; 5 = much safer)
- AFR aircraft responsible for separation was only marginally acceptable

  (M=2.9, 1 = completely unacceptable, 5 = completely acceptable)
- Concerns
  - automation dependency
  - situation awareness of AFR aircraft
  - near-term AFR-IFR conflicts
  - overall traffic density

Concluding Remarks

- Trajectory-based ATC (as tested)
  - Potential for significant capacity increase (~1.5 x)
  - Improves traffic flow management and efficiency
  - No negative safety impact
  - Well accepted by the controllers
- Mixed Operations (as tested)
  - Potential for dramatic capacity increase (2x to 3x)
  - Can accommodate TFM constraints
  - Safety still unclear
  - Less acceptable to controllers
- Trajectory-based ATC can build the foundation for many future concepts including mixed operations

END