

Interval Management

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ADS-B In ARC demonstration

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Interval Management

- IM covers a large amount of work
- Langley's detailed expertise has been on the flight deck side but we have input to how the ground side works. Without a solid Ground Interval Management tool, IM will be very limited.
- Work over the last 35 years has explored a variety of airborne spacing concepts and technologies.
- Talk about our work in:
 - FIM-S for arrivals
 - IM-DS with enhanced vision
 - IM-DS for arrivals (FIM-S enhancement)
 - IM-DS for parallel approaches (or Paired Closely Spaced Parallel Approaches)

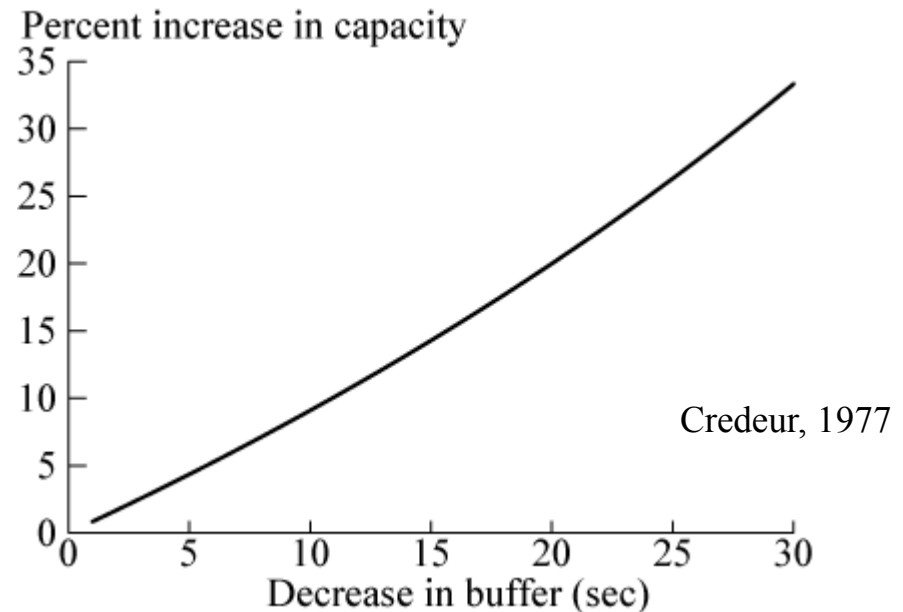
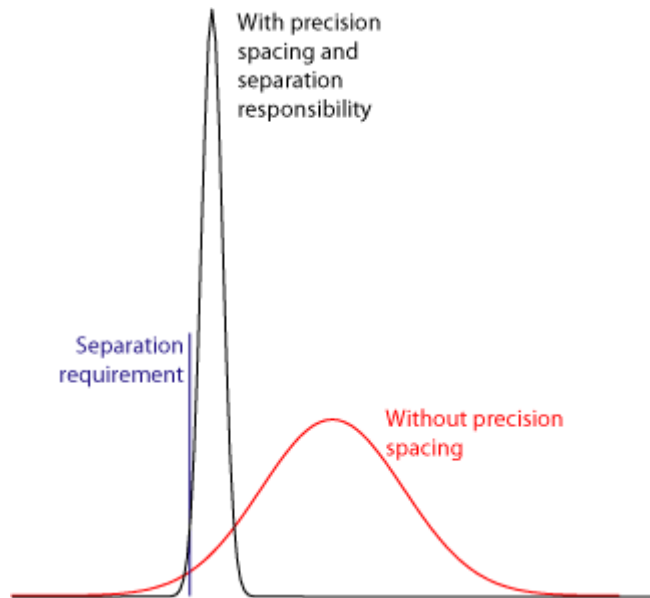
Community Involvement

- Leadership in FIM-S Safety and Performance Requirements development
 - Concept (OSED) lead
 - Continued contributions as FIM-S moves to MOPS
- Original participant in what is now the IM Working Group in SBS Office
 - Contributed concept and procedures
 - Shared display research and algorithms with ACSS
 - Key player in MOPS validation / flight trials
 - Key player in IM-DS concept of operations development
- Continued cutting edge research into the possible uses of IM

INTERVAL MANAGEMENT FOR SPACING

NASA's Motivation

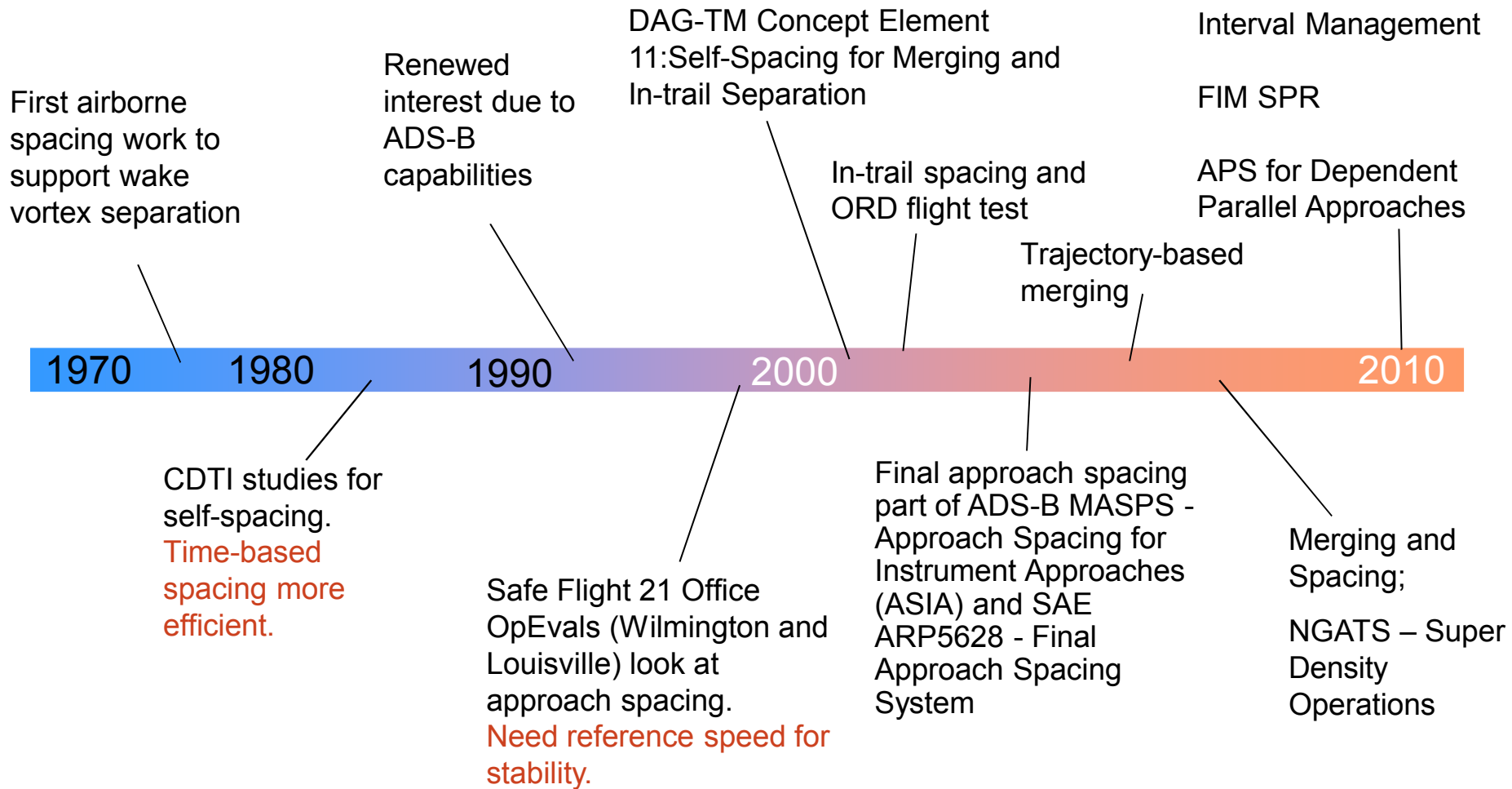
- Our motivating focus has been to increase runway throughput by reducing the necessary spacing beyond separation requirements that ensure a given level of safety.



Simulations show 10-20% increase in throughput based on LGA traffic mix [Hammer and Wang, 2001]

A delivery accuracy (standard deviation) of 3-5 seconds seems possible.

Past Langley Research



Airborne Precision Spacing: Basic Assumptions

- Airborne Precision Spacing is NASA's concept for IM-S for arrivals with possible dependent runways.
- The controller has access to a sequencing and scheduling tool that provides IM Instruction information
- IM Aircraft has FIM-S equipment that supports two-target operations
- ADS-B is used for airborne surveillance
 - Desire to add planned final approach speed
 - Accuracy and integrity requirements set in SPR independent of link
- All aircraft are on known trajectories that are shared between parties
 - RNAV arrivals to the ILS (current assumption)
 - Planned final approach speeds are shared between aircraft
- Up to two aircraft can be identified for IM
 - One is a precise interval, the other a “no closer than”

APS: Basic Procedures

1. Controller decides to use airborne spacing
 - Non-IM Aircraft can be controlled normally or given an RTA
2. Controller instructs flight crew to begin spacing
 - Target aircraft ID, spacing interval, scheduled time of arrival (if needed)
3. On-board system provides speed guidance to the crew
4. Controller monitors situation for separation and efficient flow
 - Intervene as necessary
5. On-board system commands final approach speed to ensure aircraft is stable at 1000 ft AGL

Spacing Guidance Approach

Aircraft are on RNAV routes with altitude and speed constraints (4D trajectory)

Computes relative ETA at threshold

Provides speed guidance to achieve desired spacing interval

Adjusts for dissimilar final approach speeds

Includes wind predictions

Speed within 10% of nominal profile for system stability

Gain scheduled to reduce “twitchiness” and enhance stability of a string of aircraft

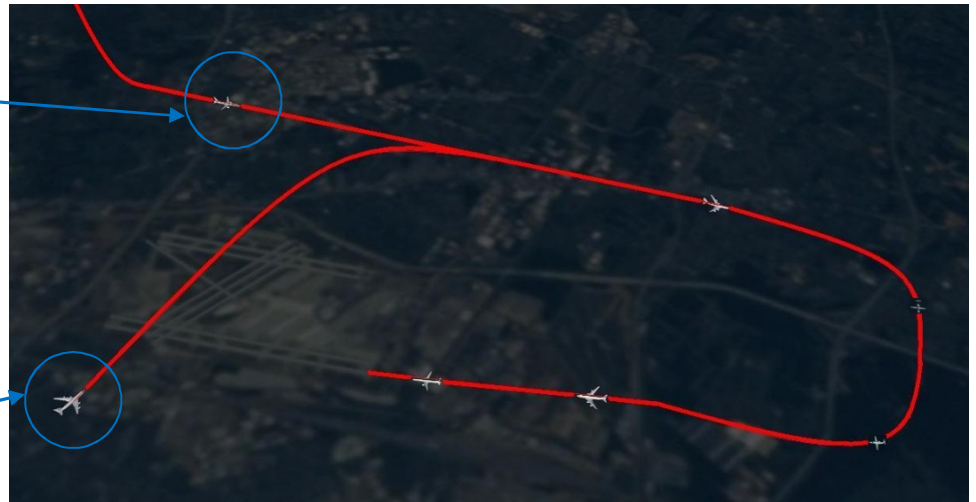
Considers aircraft configuration limits for speed changes

Operations are designed to be stable with long arrival streams

Lead:
time to go = 650 s

25 seconds early at threshold
→ Slow down 5 knots

Ownship:
time to go = 725 s



Overall IM Performance

Study Type	Spacing Mean	Spacing Std. Deviation
Fast-time studies of non-disruptive cases	< 1.0 sec	1.8 – 4.2 sec
High-fidelity, in-trail piloted simulation	1.0 sec	1.7 sec
Medium-fidelity, merging and in-trail piloted simulation	0.8 sec	4.7 sec
Flight evaluation of in-trail spacing	0.8 sec	7.7 sec

Controller Field Data

DTW multilateration data ^a	27 sec
DFW RADAR data ^b	19.6 sec

^a B.G. Jeddi, et al, 2nd ICRAT conference Belgrade 2006

^b M.G. Ballin, H. Erzberger, AIAA-96-3723, 1996



Demonstration

- Check-out scenario for up-coming APS experiment (IM-S for arrivals with two-targets)
- Tool and scenarios still in development

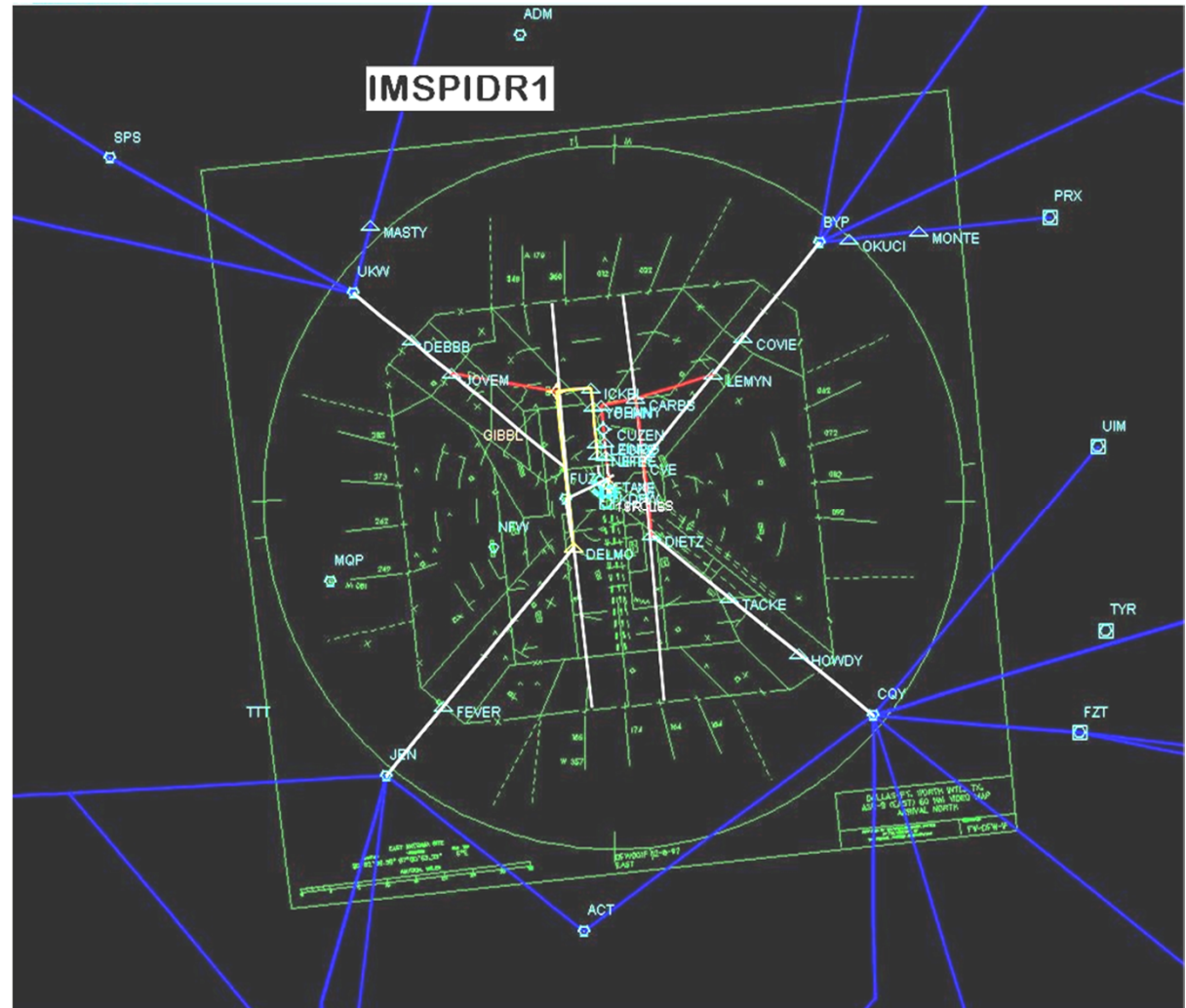
Arrival Route Design

Arrivals to 18R and
17C at DFW – 8800 ft

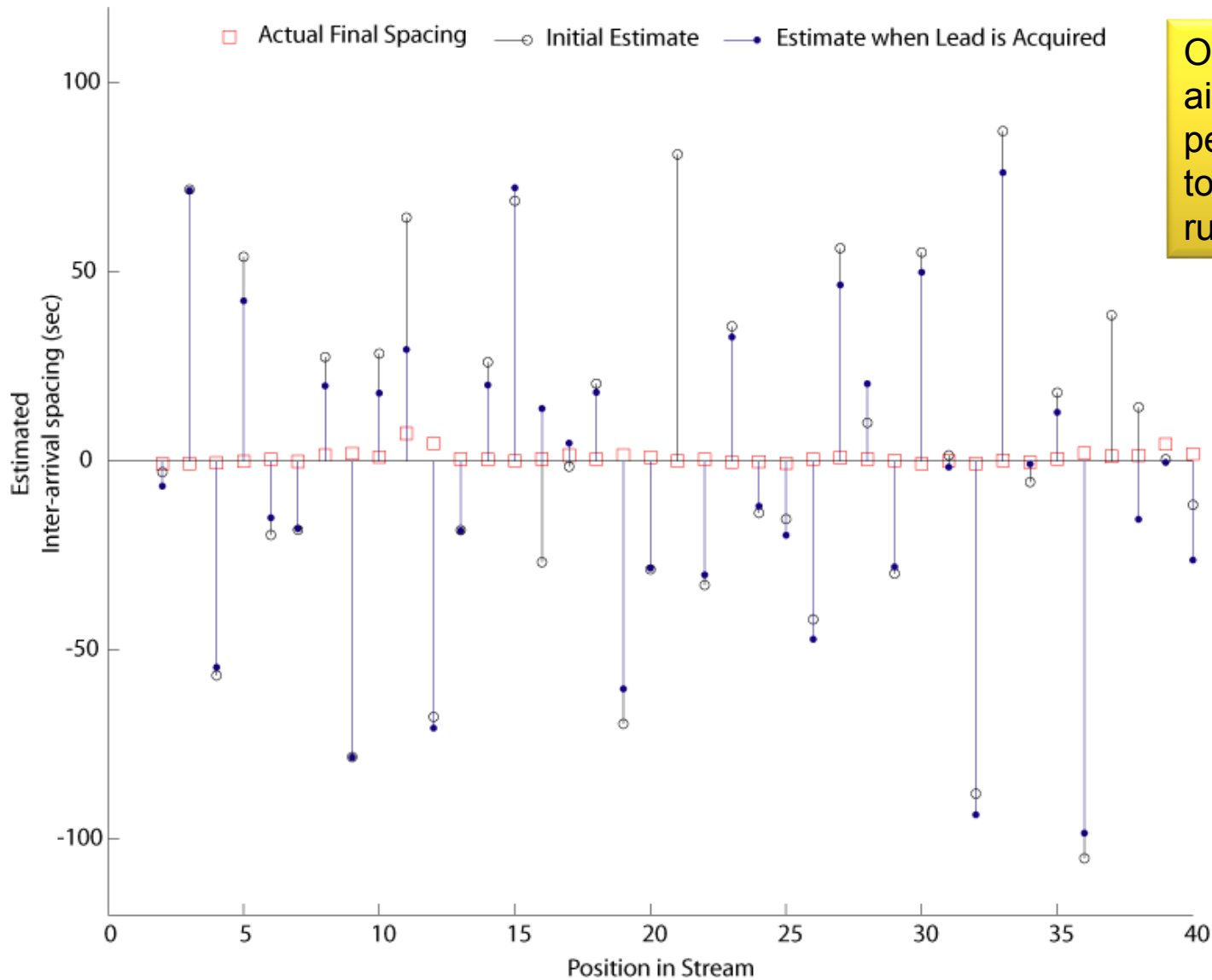
Chosen to support
experiment timeline

Separate batch study
looking at 2500 ft and
5100 ft runway
separations

OPDs with altitude
separation enforced at
turn to final



Spacing Performance

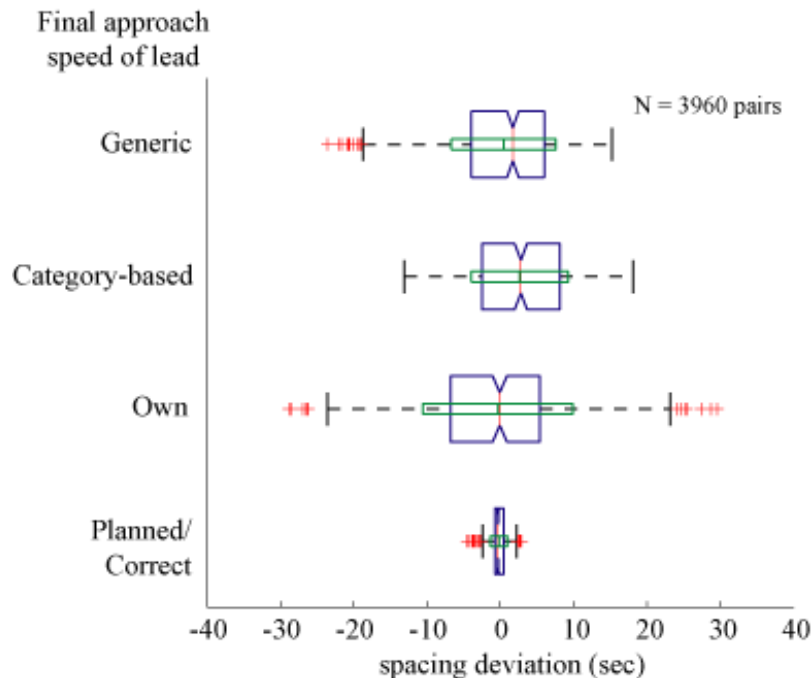


One run of 40 aircraft stream performing OPD to a single runway.

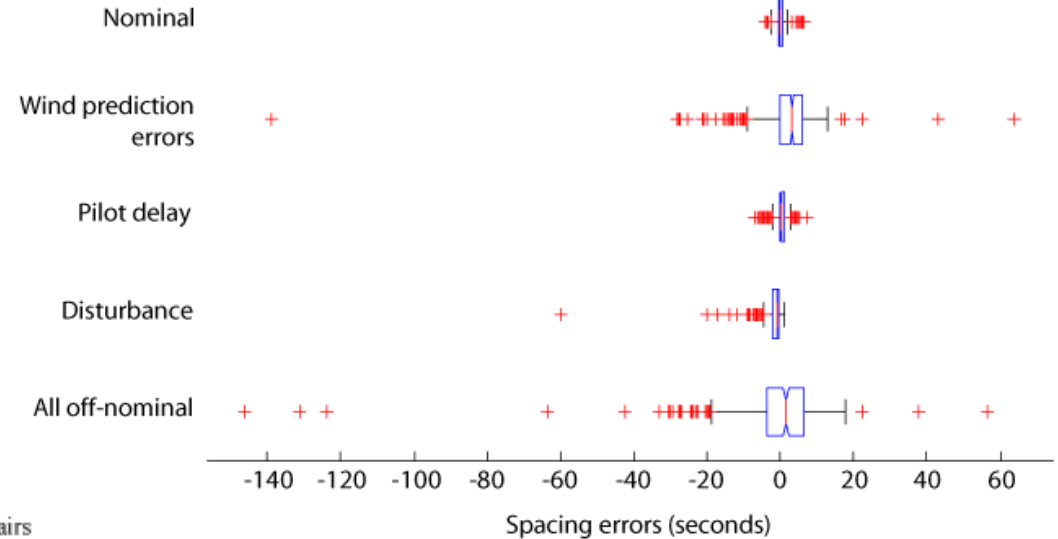
Largest Challenges

Largest problem seen to date is having an accurate schedule.

Wind predictions errors can be overcome once paired up for IM



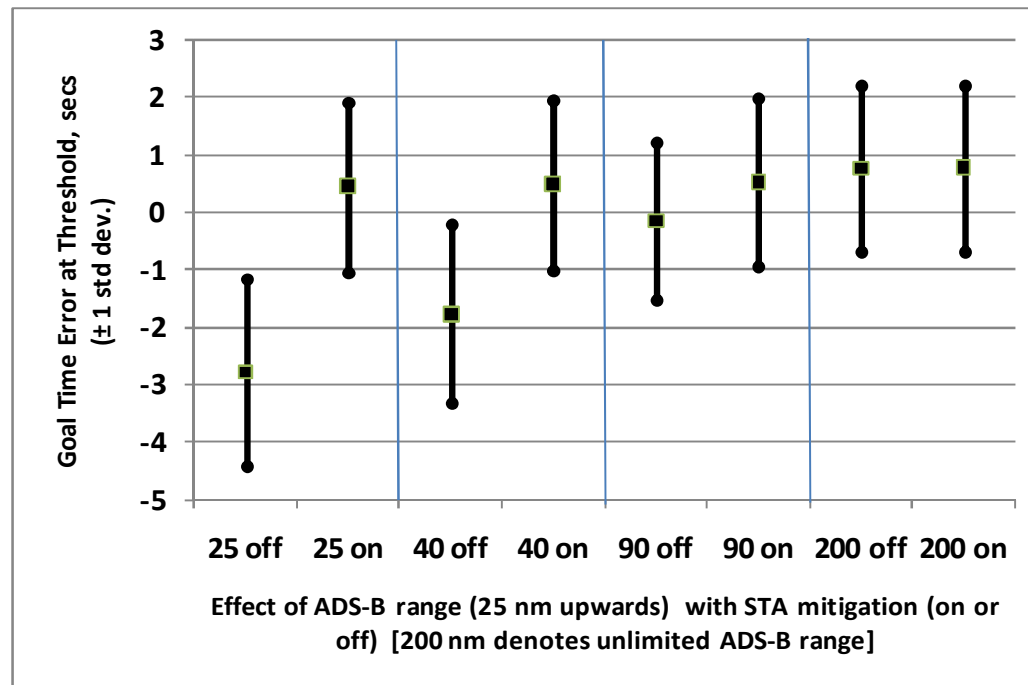
Test condition



Use of Planned Final Approach Speed is necessary to get precise spacing for high-throughput.

Mitigation for ADS-B range limitations

- The STA Mitigation Tool is most effective at limited ADS-B ranges between 25 and 40nm.
- At 90 nm and above there no noticeable difference in performance with or without STA mitigation.
- STA Mitigation significantly improvements APS at low ADS-B ranges :
 - ADS-B range of 25nm STA mitigation improves goal-time-error from -3sec to +0.5sec.
 - The vertical bars in the above graph show 1 std off the mean values recorded, and it shows that at 25 nm the difference in means is statistically significant, which draws the conclusion that the STA mitigation algorithm works for limited ADS-B ranges.



Behavior of Spacing with OPDs

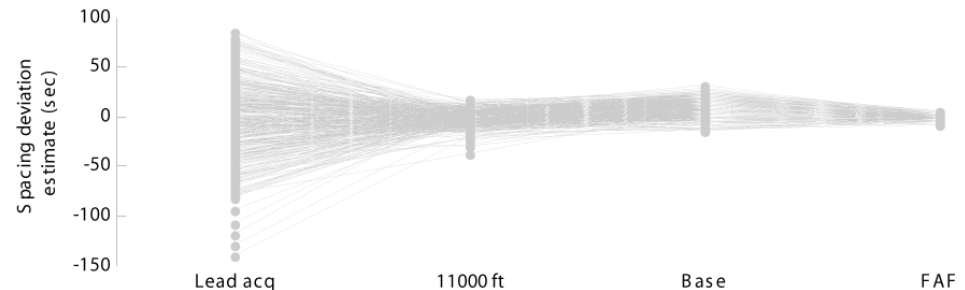
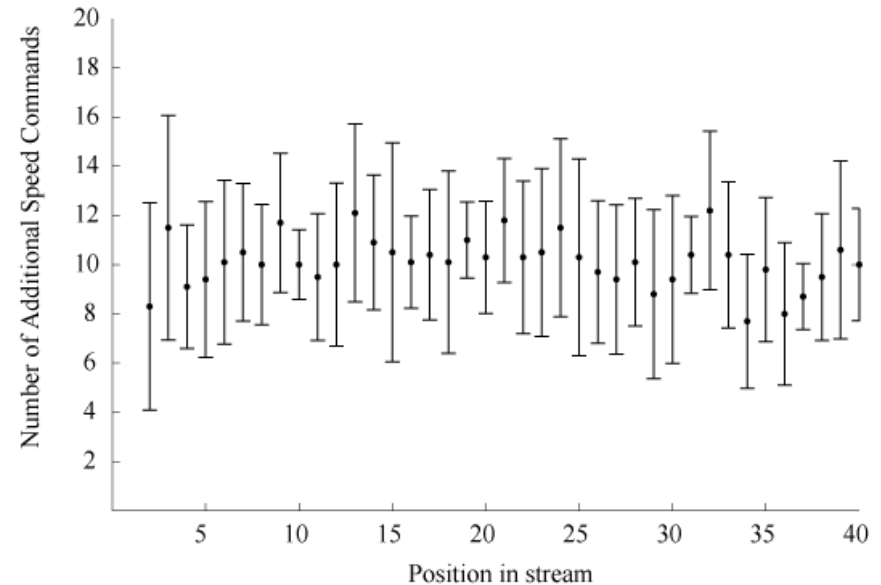
Can OPDs be combined with IM or do the two ideas negatively interact?

Simulation scenarios were 40 arriving aircraft along 4 routes (1 en route, 2 low altitude merges) to one runway starting 350 nm out

Can achieve high delivery precision even with limited speed authority ($\sigma = 1.2$ sec)

System behavior is stable (no effect based on location in stream and acceptable number of speed changes [$\mu=10$ for 50 min])

Spacing can overcome large initial spacing deviations



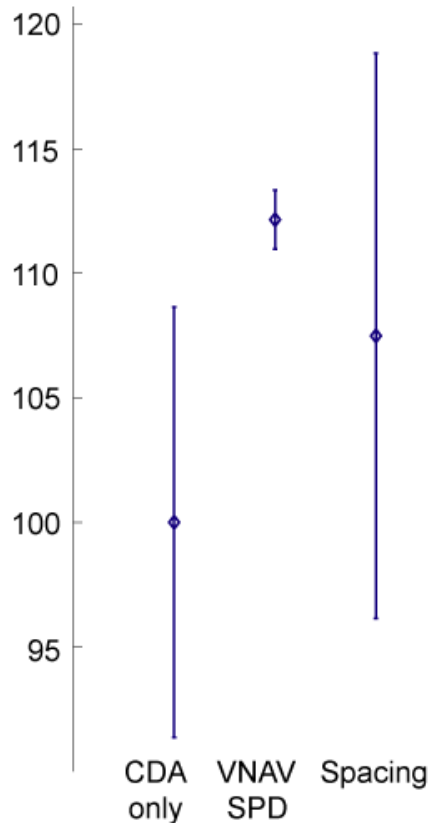
Fuel and Time Savings

Does the additional speed adjustments use more fuel or take more flight time?

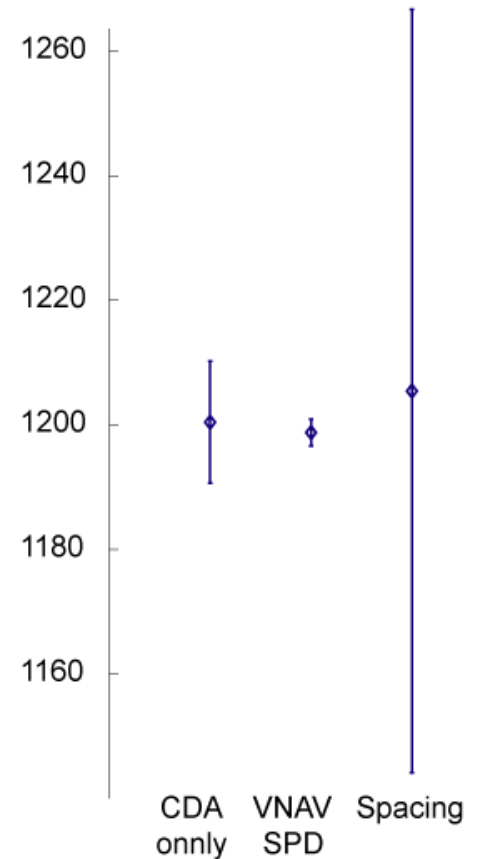
Flight time was insensitive to IM or unconstrained OPD

- Wider spread for IM was due to shifts in the schedule.
- Performed IM in Speed Intervene while OPD was FMS guidance.
- VNAV mode had an affect on fuel use; IM impact was insignificant.

Fuel Usage (normalized)
Last 110 nm flight distance



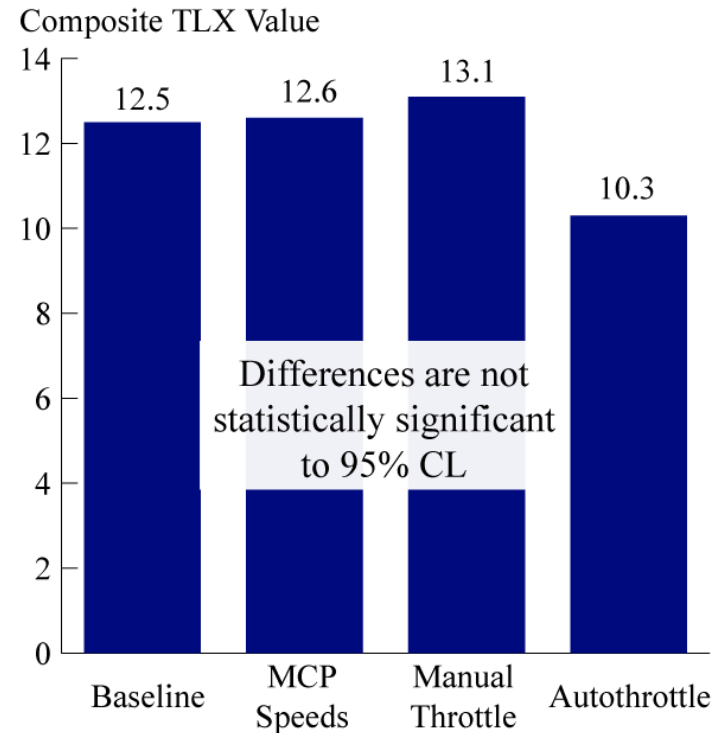
Flight Time (sec)
Last 110 nm flight distance



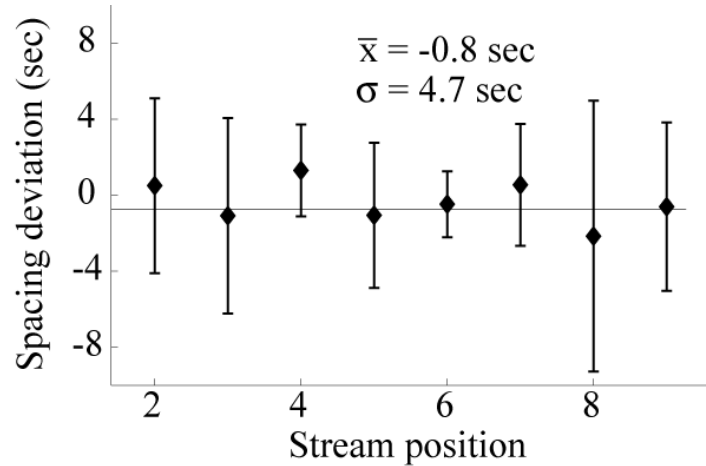
Pilot Feedback and Workload

Eye tracking data in the full-mission simulator showed little to no change between the dwell time and scan pattern for the primary displays and out the window between current day operations and spacing operations. NASA TLX for workload reveals no perceived difference in workload.

Acceptability of the spacing tool, heads-down time and confidence in the speed guidance were all high (greater than 6 on 7 point scale). Questionnaires from workstation simulation shows no perceived change in workload between in-trail and merging operations. Speed change count was consistent between merging and in-trail and workstation and full-mission simulations.

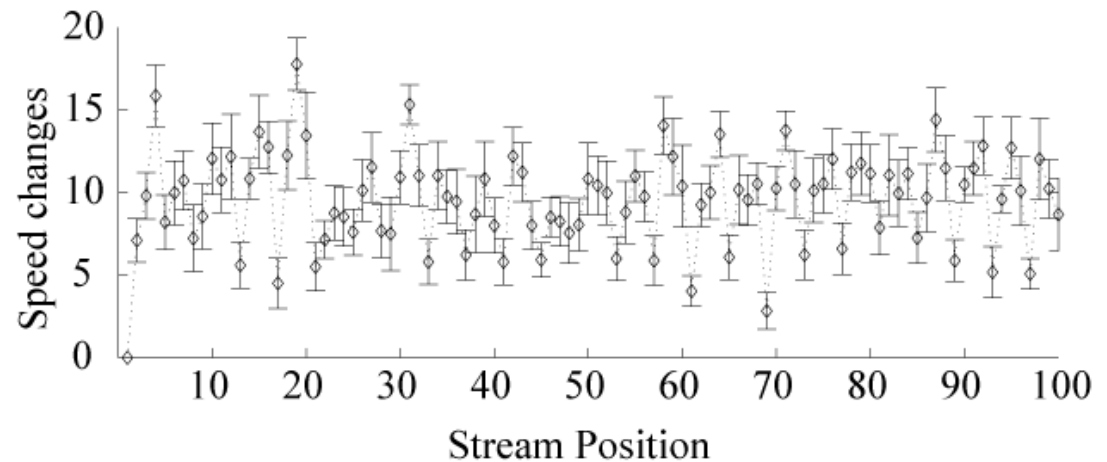


Stream Stability

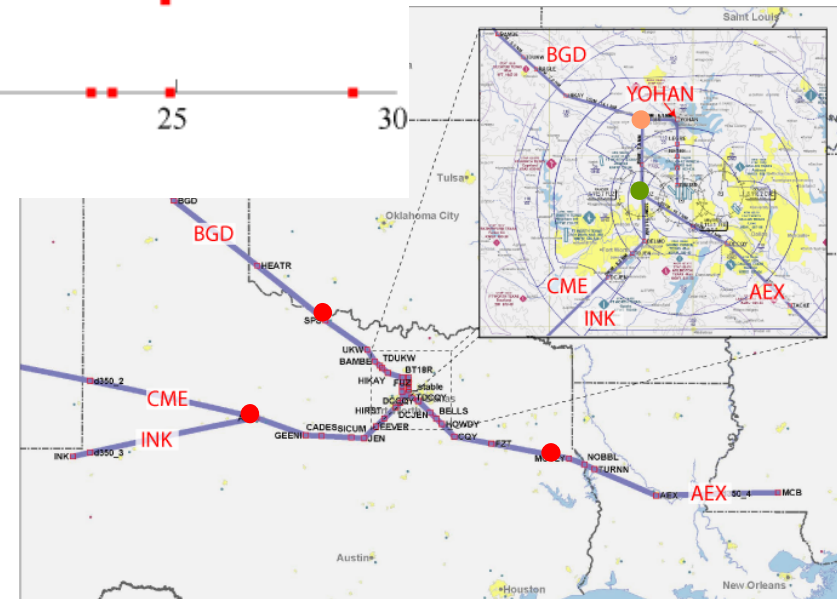
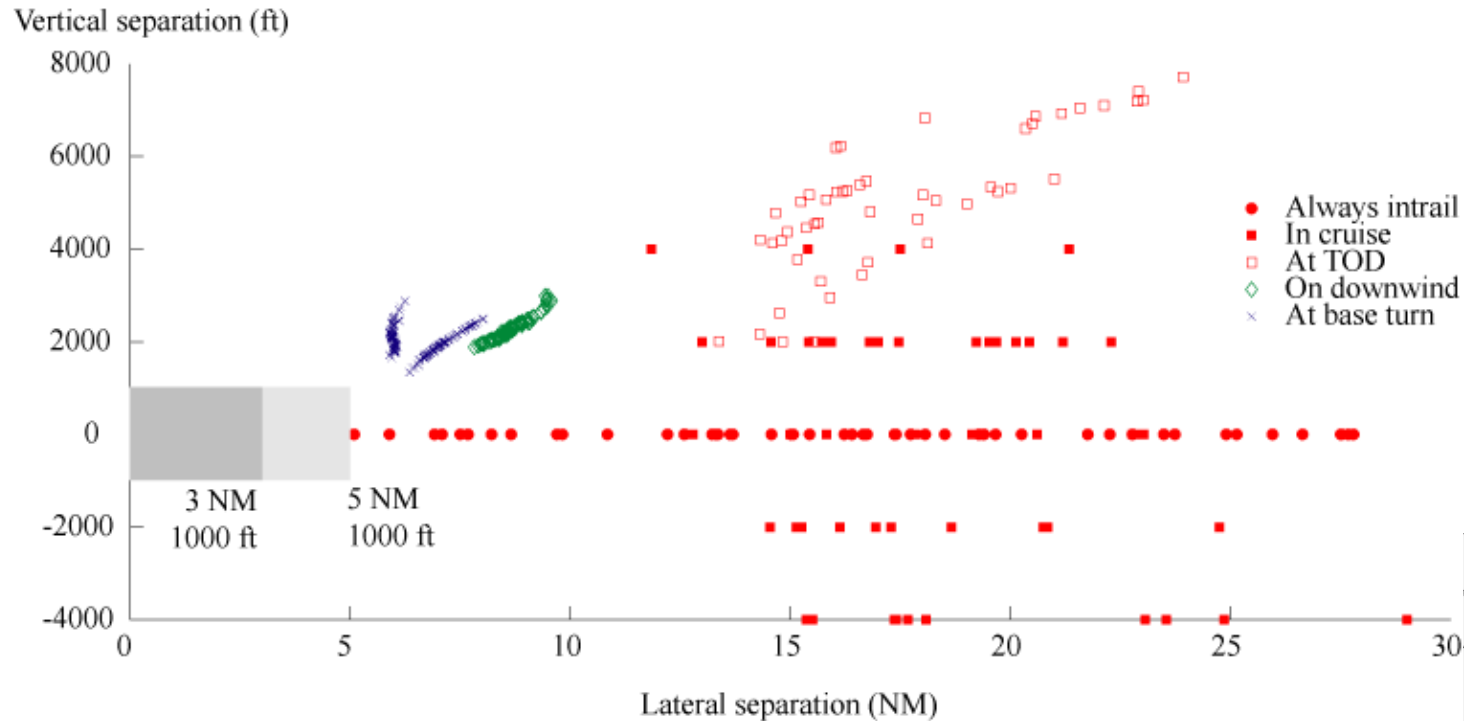


No destabilizing effect
has been seen

- For spacing operations to be of use to the ATC system and provide the expected benefit, the system must be stable to long streams of spacing aircraft.
- Stability is measured by performance (achieved spacing and speed changes) invariant to stream position.
- Three studies have looked at stability:
 - 100 aircraft stream in fast-time batch
 - 40 aircraft streams in CDA fast-time batch
 - 9 aircraft streams in piloted, workstation-based simulation



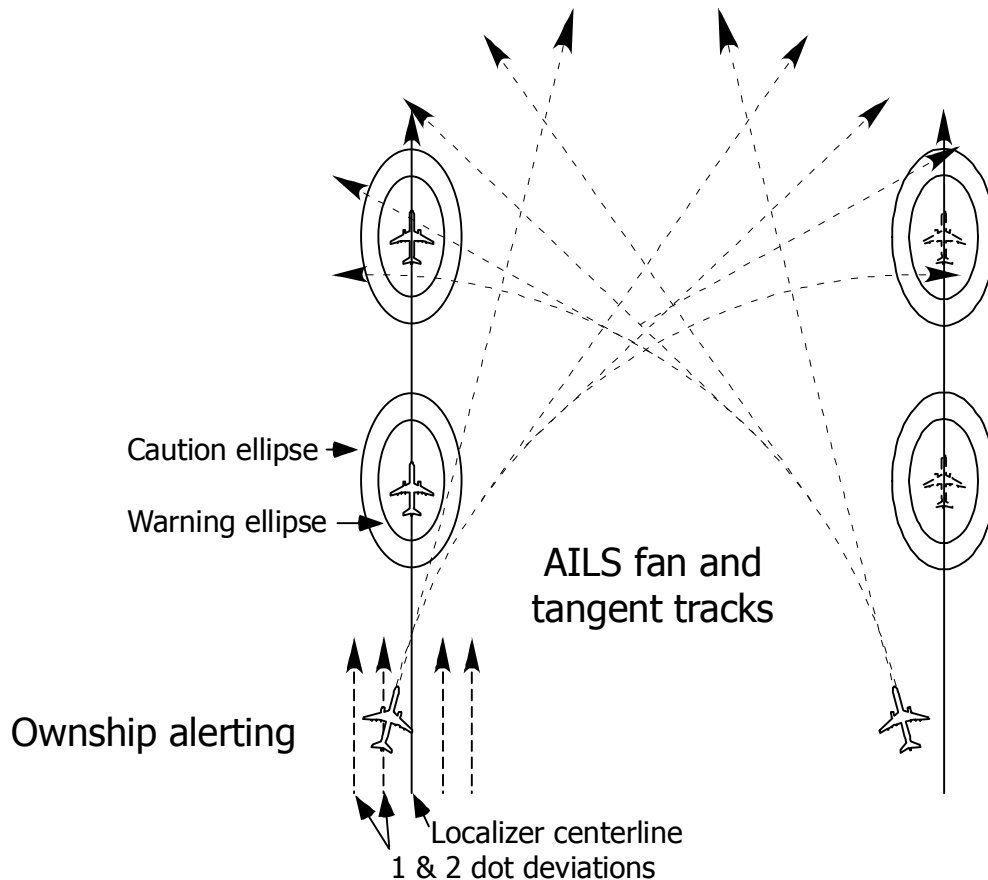
Separation at the Merge Point



IM-DS Foundational Work

- In the early 1990's, NASA created the Airborne Information for Lateral Spacing (AILS) concept and, in partnership with Honeywell, validated the concept through simulation and flight test
 - For independent, closely spaced parallel runway operations
 - Approach path design and highly accurate navigation to reduce possibility of intrusion.
 - Onboard use of ADS-B to detect deviations of other aircraft from expected path and alert pilot to perform emergency escape maneuver.
- In 2008, the FAA proposed the Simplified Aircraft-based Paired Approach (SAPA) concept, and NASA is helping develop and assess this concept.
 - For dependent, closely spaced parallel runway operations
 - Highly accurate navigation and coupled autopilot to reduce possibility of intrusion.
 - Paired coupling between wake interaction zones supported by advanced guidance.

AILS Alerting

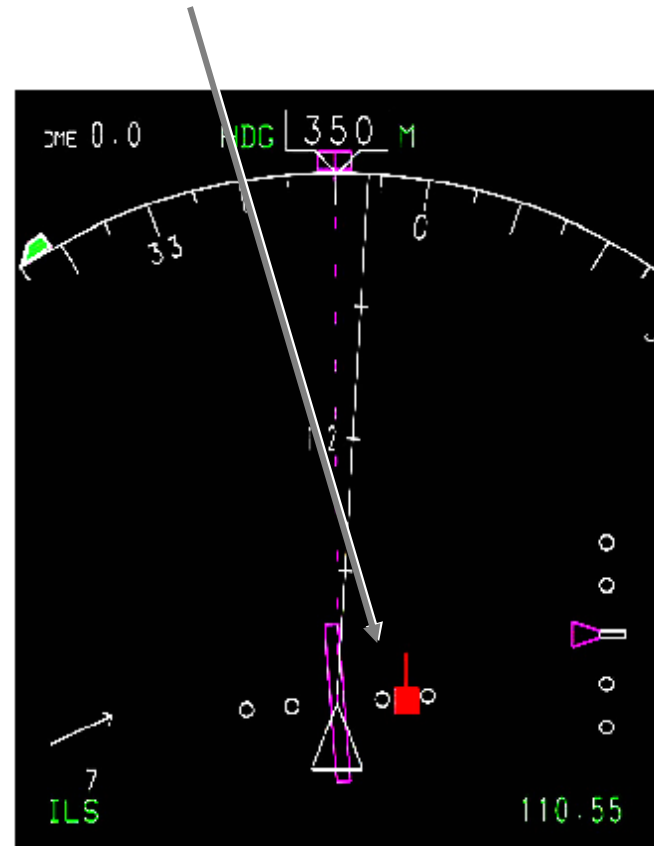


ALERT	Ellipse size (downrange, cross-range, vertical) ft	Time projection sec
<u>Threat AC</u> PATH CAUTION	±5000 ±1800 ±1800	30
<u>Threatened AC</u> TRAFFIC CAUTION	±3500 ±1300 ±1300	22
<u>Threat AC</u> PATH WARNING	±3400 ±1250 ±1250	21
<u>Threatened AC</u> TRAFFIC WARNING	±2500 ±900 ±900	16

Simple Display Additions



TCAS-like additions to support AILS



AILS End Point

- 1999 simulation results validate concept
Miss-distance > 1000 ft.
Acceptable to all test-subject pilots
Pilot reaction times within acceptable norms
- 1999 flight test results validate simulation results
- FAA AFS-420 study: *Comparative Study Of Airborne Information For Lateral Spacing (AILS) System With Precision Runway Monitor (PRM) System*
- RTCA SC-186 analysis of safety of generic CSPA operations
- Still some open issues

SAPA Paired Coupling

- SAPA supports dissimilar final approach speeds as much as 10 kts or more within a pair of coupled aircraft
- Using onboard spacing guidance, pair is positioned at stabilized approach point with faster aircraft behind slower aircraft, but ahead of wake interaction boundary
- Faster aircraft can move ahead and pass slower aircraft during final approach and landing

