Raytheon
Network Centric Systems

Evaluation of the Terminal Area Capacity Enhancing Concept

February 10, 2004

Virtual Airspace Modeling and Simulation Program
Technical Interchange Meeting #4

K.D. Arkind
M.E Miller

Agenda

- TACEC Core ideas
- Anticipated benefits
- Approach
- Metrics
- Results and lessons learned
- How the results further the concept description
- Challenges

TACEC Overview

Raytheon
Network Centric Systems

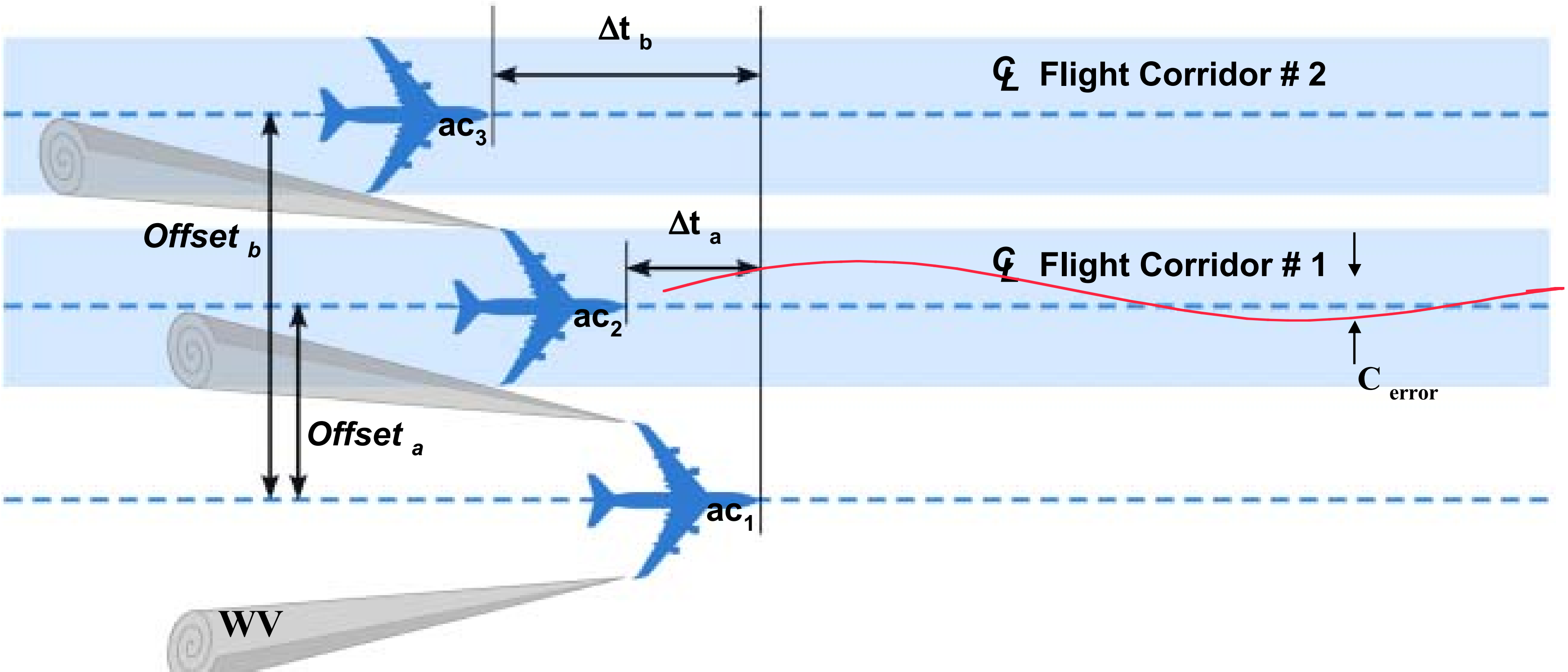
- Primary capacity constraints for terminal area operation are;
  - Wake Vortex Hazard avoidance
  - Runways
- TACEC addresses both areas with the following core ideas:
  1.) Introducing the concept of closely spaced final approaches defined by wake hazard free "Flight Corridors"[1]
  2.) Optimize terminal area flight paths to stage aircraft for final approach
  3.) Utilize DGPS based auto-land for all weather operation
  4.) Use today's closely spaced parallel runways and/or build additional runways "between" them.

1. Rossow, V. "Use of Individual Flight Corridors to Avoid Vortex Wakes", AIAA AFM Conference, August 2002

Core idea #1
Instead of in-trail spacing to avoid wakes

Raytheon
Network Centric Systems

Flight Corridors avoid WV by eliminating uncertainty



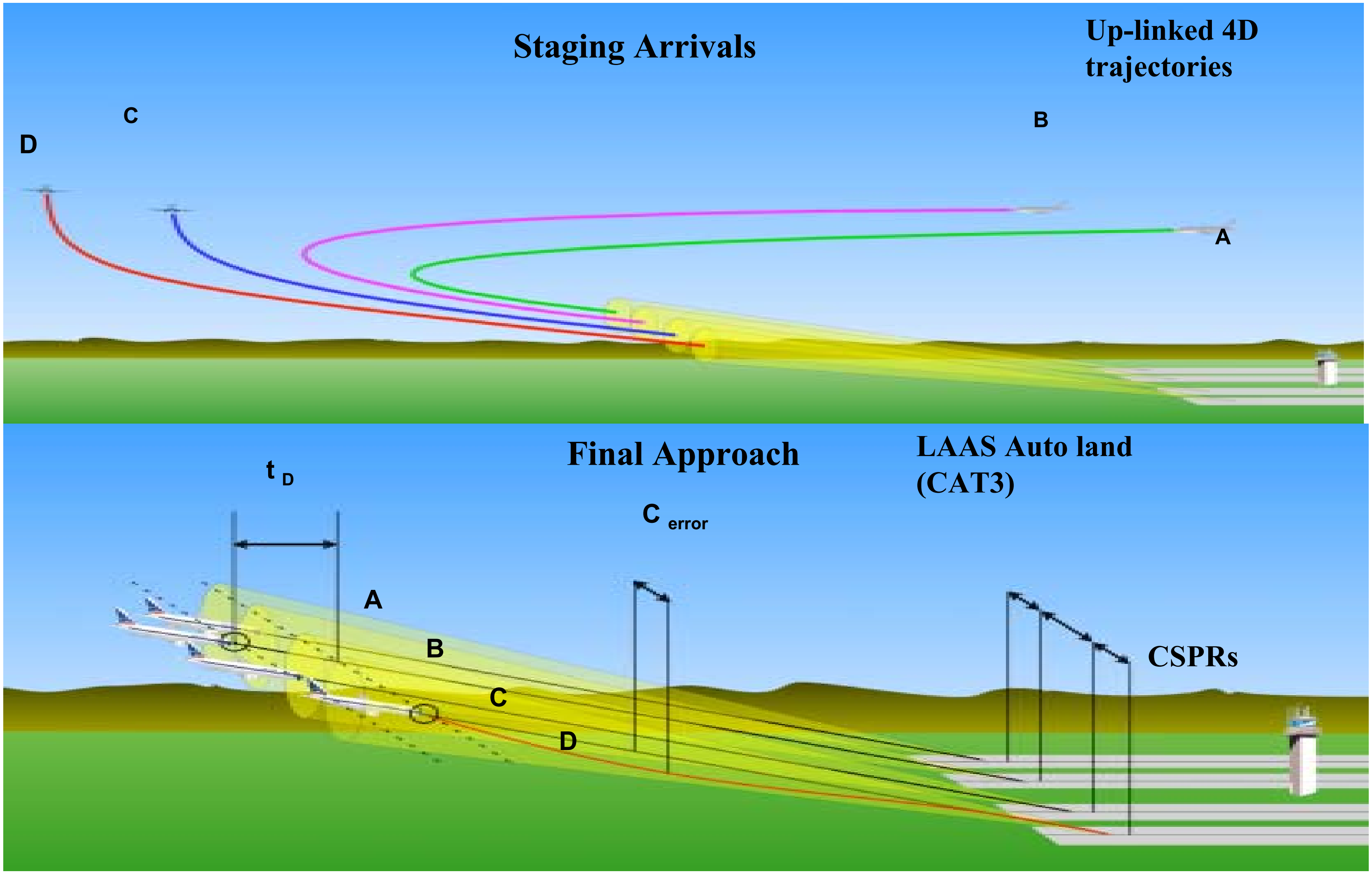
Offset $_a$ **= WV** (ac_1, t) **+ C** $_{error}$ (ac_2, t)

Offset $_b$ **= WV** (ac_1, t) **+ WV** (ac_2, t) **+ C** $_{error}$ (ac_2, t) **+ C** $_{error}$ (ac_3, t)

Note: WV is also dependent on atmospherics

Core idea #2 & 3
Implementation is a Terminal Area Challenge

Raytheon
Network Centric Systems



Core idea #4
Adding Runways

- **Establish Independent, all weather runway usage with spacing minimums of 500 ft.**
  - **Build new runways between existing parallels**

    or
  - **Utilize existing closely spaced dependent runways**

AIRPORT	RW	SPACING (ft)
FORT LAUDERDALE	9L/9R	4000
DETROIT	3L/3C	3800
SALT LAKE CITY	16/17	3700
PHOENIX	8/8R	3565
MEMPHIS	18L/18R	3400
RALEIGH-DURHAM	5L/5R	3400
MINNEAPOLIS	30L/30R	3380
PORTLAND	10L10R	3100
KENNEDY	4L/4R	3000
INDIANAPOLIS	5L/5R	2525
DETRIOT	3C/3R	2000
ORLANDO	18L/18R	1600
BOSTON	4L/4R	1500
PHILADELPHIA	9L/9R	1400
ST. LOUIS	12L/12R	1300
	17L/17R	1200
DALLAS-FT WORTH	18/18R	1200
PITTSBURGH	10C/10R	1200
	8L/8R	1000
ATLANTA	9L/9R	1000
HOUSTON	14L/14R	1000
LAS VEGAS	7L/7R	1000
NEWARK	4L/4R	900
SEATTLE	16L/16R	800
LAX	7L/7R	750
	1L/1R	750
SFO	28L/28R	750

Benefits

- **Primary benefit is the significant capacity increase available by using all possible runways, in all weather for both arrivals and departures.**
  - **Reduces delays, hence operating costs for airlines**
  - **Increases schedule reliability for travelers**
- **Implementing TACEC takes advantage of existing airport facilities**
  - **Reduces infrastructure investment needed to build new runways**
  - **Land acquisition not necessary to add new runways**

Self Assessment Approach
Track 1 - Evaluate key performance requirements

- **Hazardous wake vortex characteristics**
  - Defining hazardous wake
  - Crosswind impact
  - Wake position verification integrity
- **Aircraft position accuracy**
  - Aircraft performance
  - Position verification integrity
  - Operating environment
  - Flight Technical Error
- **Safety**
  - Blunder during approach
  - Terminal airspace conflict detection
- **Human performance**
  - Cockpit visualization
  - Ground monitoring

Feasibility assessment for implementing TACEC

Self Assessment Approach

Track 2 - Use ACES to assess terminal area capacity growth and the NAS-wide impact

Raytheon

Network Centric Systems

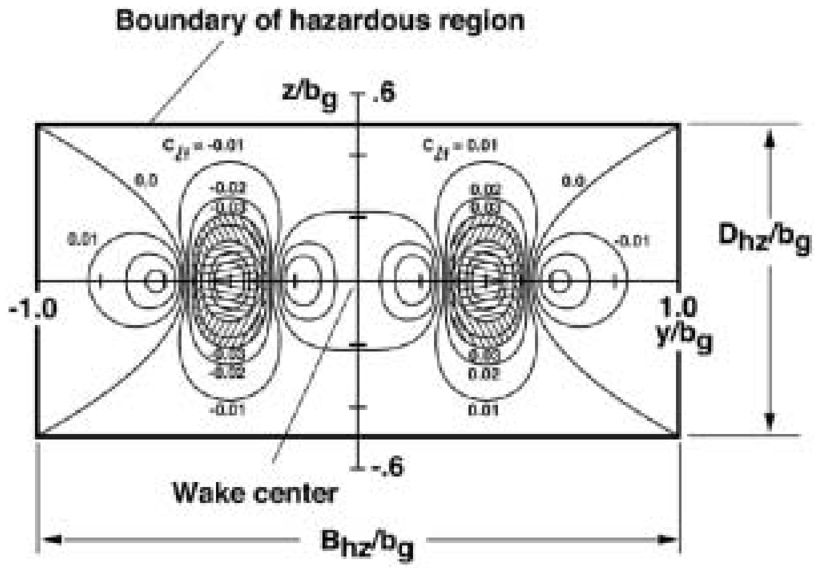
- **What could the airport's arrival/departure rate become with TACEC?**
  - **Time window of arrival time differences of 60 to 300 seconds**
  - **Geographic arrival points constrained to 90 degrees of assigned runway, or unconstrained arrival points.**
  - **Number of aircraft in parallel final approach, 3, 5 or no limit.**
  - **Constraining paired aircraft types in various ways.**
  - **Time window of departure time difference of 60 to 300 seconds**
  - **Departure gate (meter fix) constrained to at least 90 degrees.**
  - **Constraining aircraft types in various ways**.

- **What is the increase in capacity of the NAS based on these new airport arrival/departure rates?**

Verify the expected capacity benefits

Performance requirements for wake hazard avoidance

- **Hazardous Wake Vortex characteristics**
  - **Defined as any vortex element that creates an overpowering rolling moment, causing an unplanned roll excursion of 5° or more on the following aircraft.**



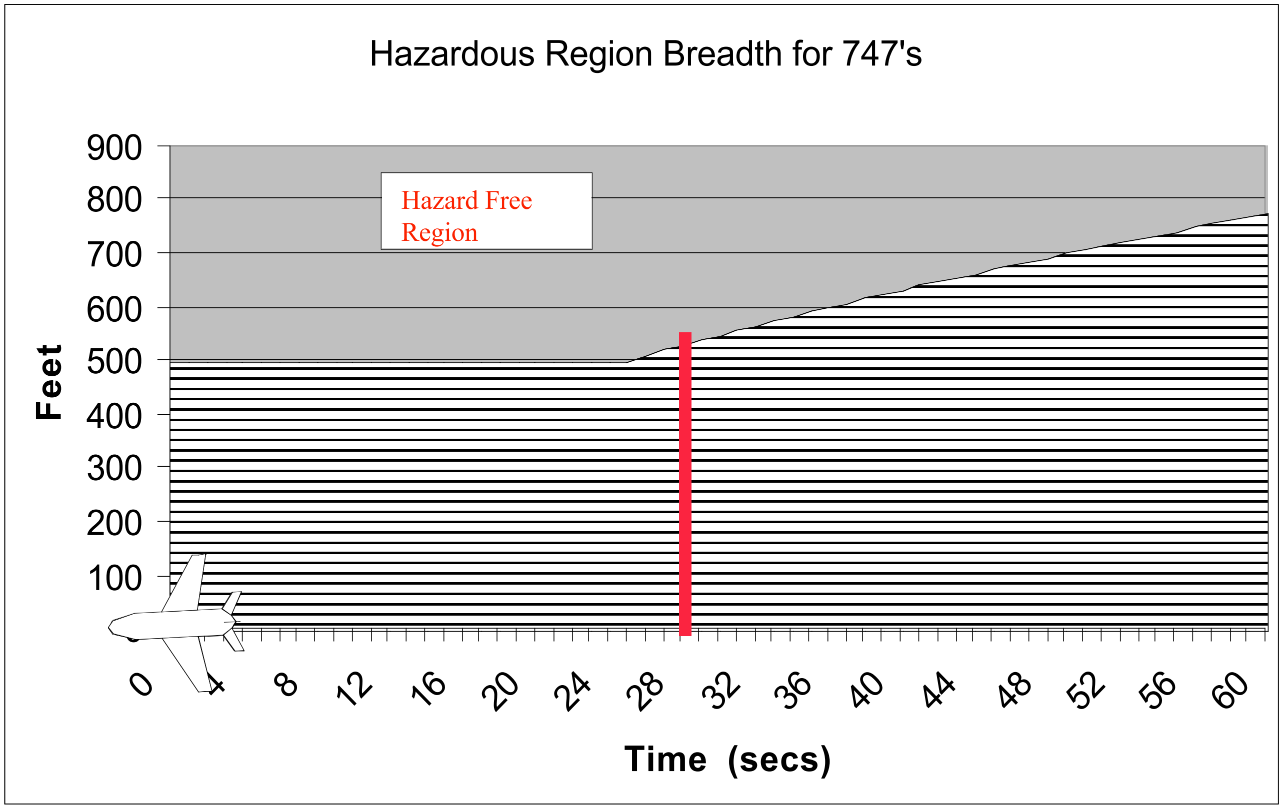
b_g = generating aircraft wingspan
b_f = following aircraft wingspan
B_{hz} =breadth of hazard region
D_{hz} = depth of hazard region

Breadth of the hazardous region is 2 x b_g where b_f/ b_g = 0.29
Breadth of the hazardous region is 2.5 x b_g where b_f/ b_g = 1.0

Performance requirements for wake hazard avoidance (cont'd)

Hazardous region spreading vs time[1]:

$$B_{hz}(t) = 0.5 b_g \mathrm{sqrt}(t)$$

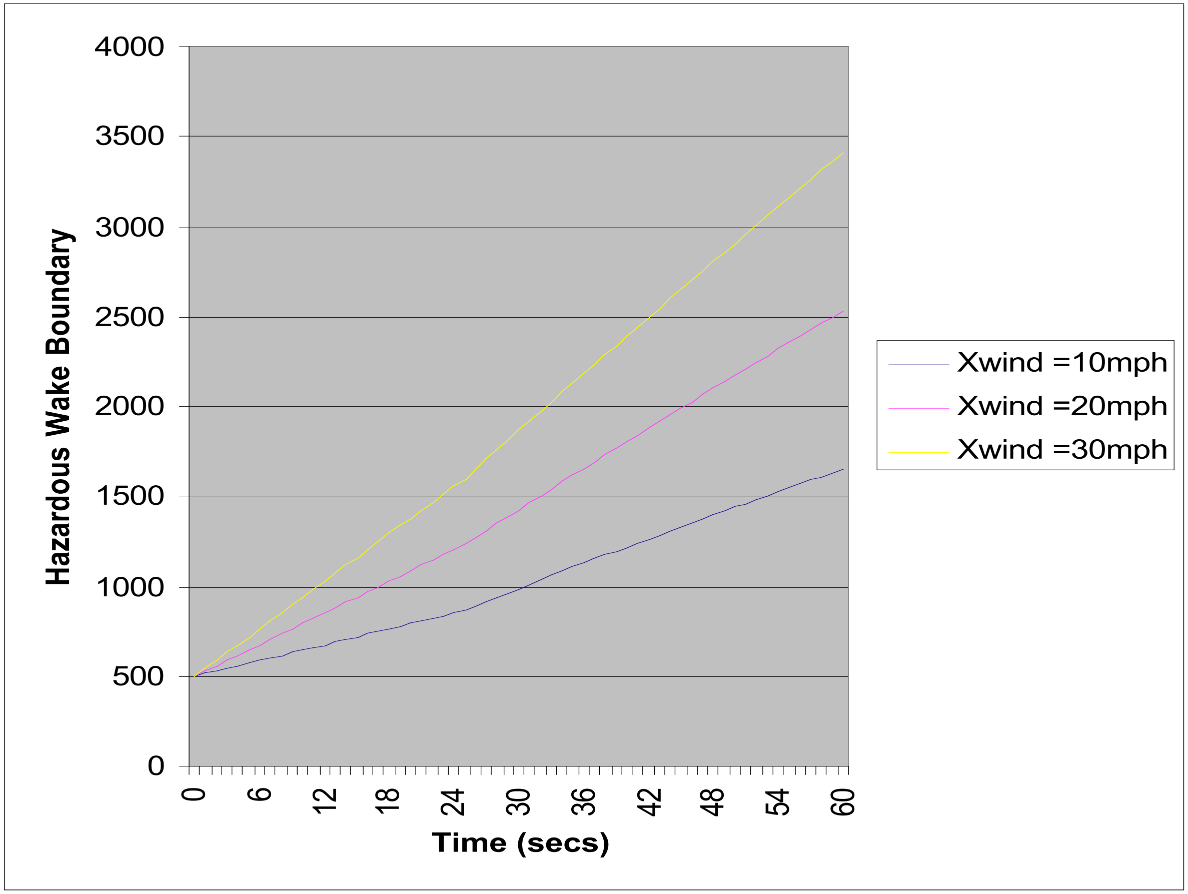


[1]Rossow V., "Implementation of Individual Flight-Corridor Concept" AIAA ATIO, Nov. 2003

Performance requirements for wake hazard avoidance (cont'd)

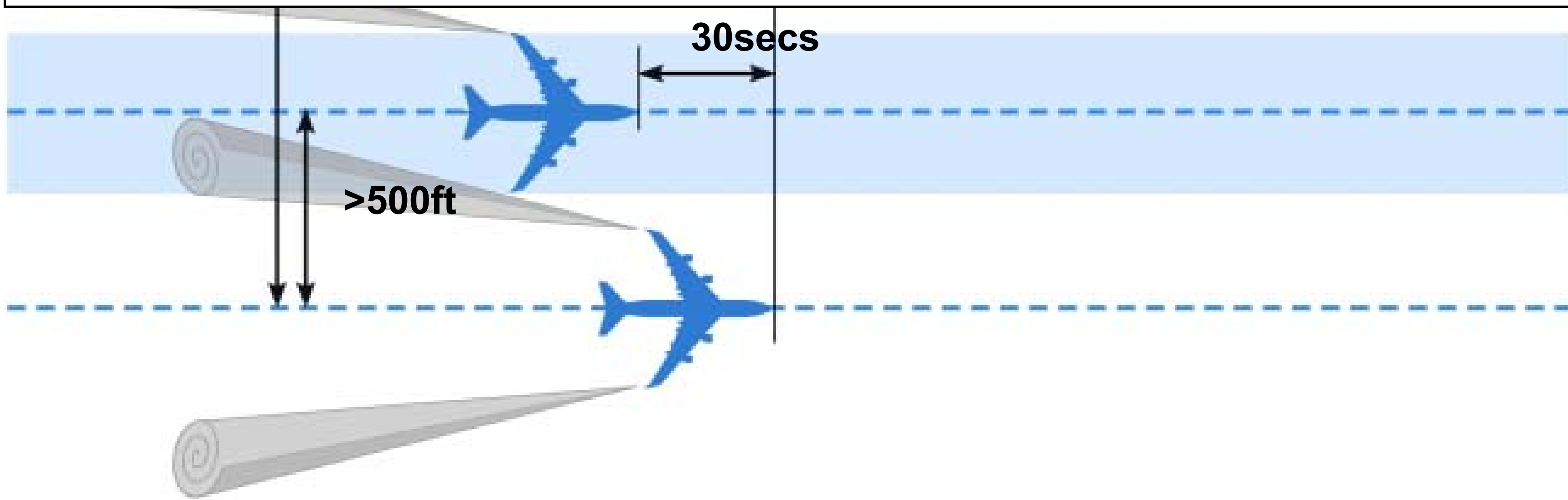
Raytheon
Network Centric Systems

Environmental impact, crosswind movement of hazardous region



Performance requirements for wake hazard avoidance (cont'd)

With zero crosswind, two 747's must be within 30 seconds of each other on final to 500 ft RCL's.........or approximately 1.5 m in trail spacing.



As crosswinds increase, RCL's must increase and/or time differential reduced….

Performance requirements for wake hazard avoidance - Key Issues

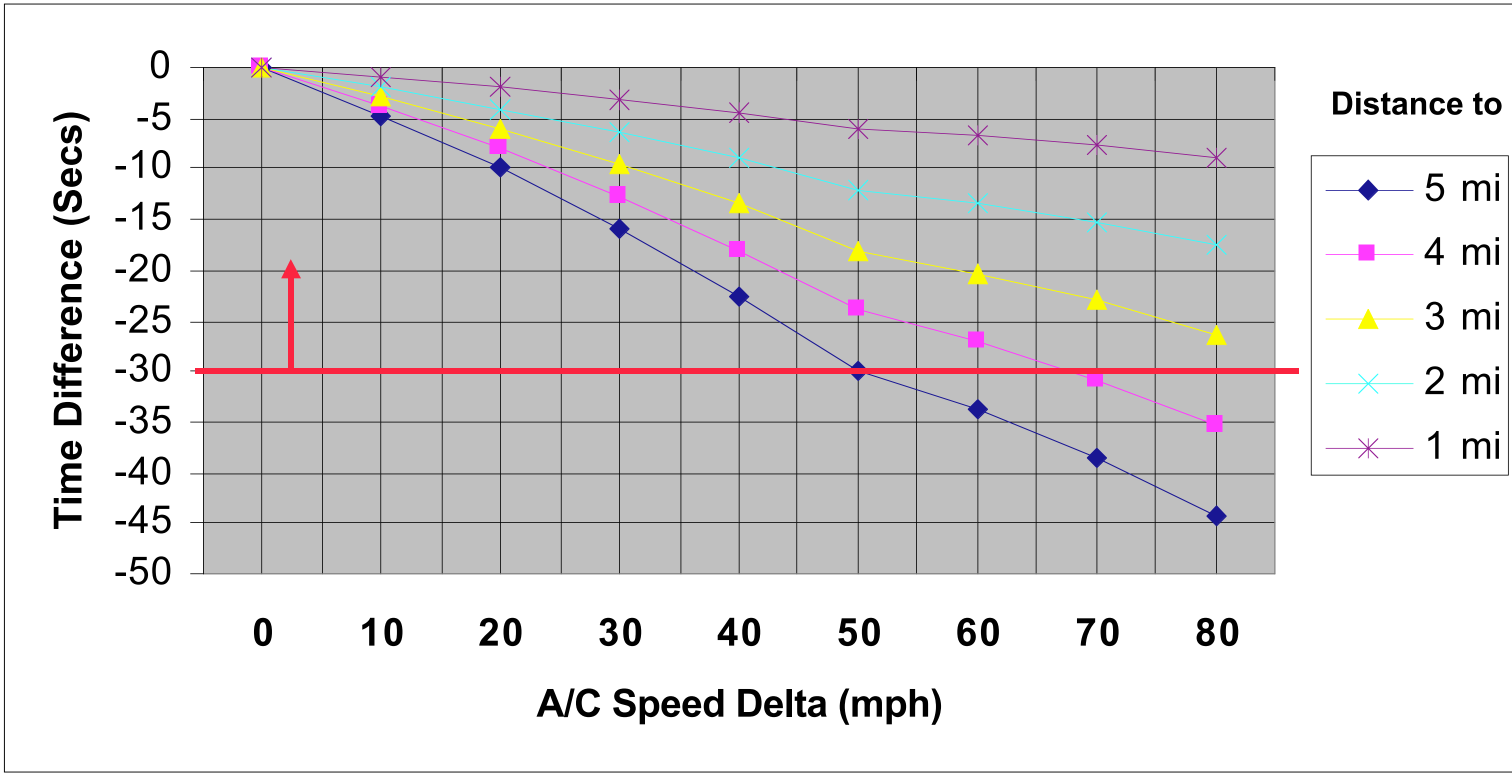
Raytheon
Network Centric Systems

- Wake position verification
  - High integrity, highly reliable terminal area environmental monitoring is required. Wind velocity in final approach region critical.
    - » Time critical wind assessment required.
  - Dynamic wake measurement/monitoring capability along approach corridor can provide additional information.
  - Current WakeVAS development can provide necessary wake hazard position assurance function

Performance requirements for aircraft position

Raytheon
Network Centric Systems

- **Aircraft performance - maintaining required aircraft to aircraft position will require groupings for both staging and final approach**
  - **Time differential at Final Approach Fix + descent delta < 30 seconds**



TACEC Operation requires grouping of similar aircraft

Performance requirements for aircraft position

Raytheon
Network Centric Systems

- **Flight Technical Error (FTE)**
  - Definition - FTE is the contribution to aircraft position error that arises from inaccurate aircraft control
  - Total System Error = Navigation + FTE
  - DGPS/LAAS will provide navigational errors in meters

LAAS Requirements

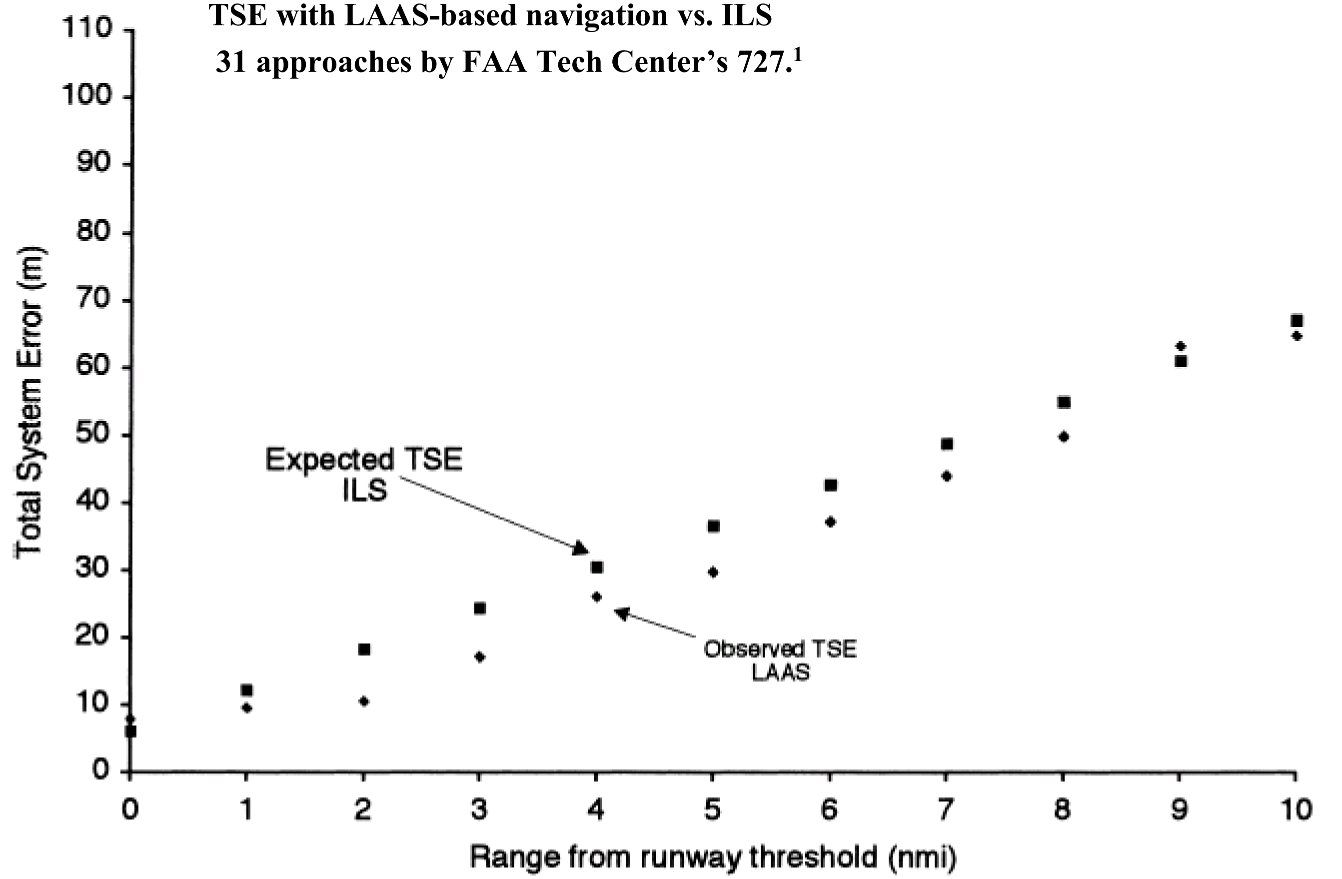
Perf. Type	Accuracy 95% (m)	Integrity risk	Continuity risk	Availability
1	4.39	$2*10^{-7}$ /approach	$8.6*10^{-6}$/15s	0.99 to 0.99999
2	2	10^{-9} /approach	4*10-6/15s	0.99 to 0.99999
3	2	10^{-9} /approach	Lat $2*10^{-6}$ /30s Ve $2*10^{-6}$ /15s	0.99 to 0.99999

Performance requirements for aircraft position (cont'd)

Required performance must come from FTE improvements

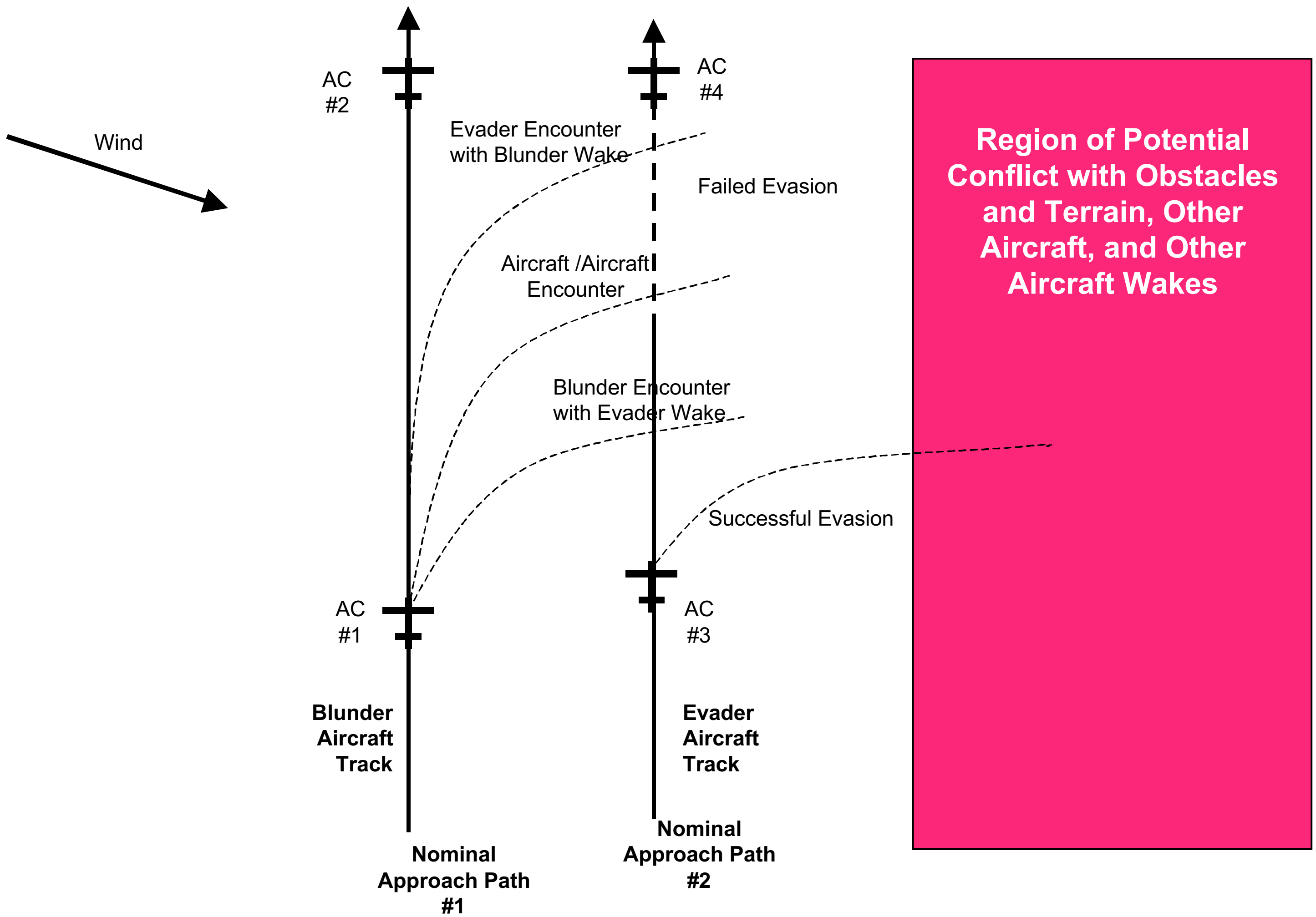
TSE with LAAS-based navigation vs. ILS

31 approaches by FAA Tech Center's 727.[1]



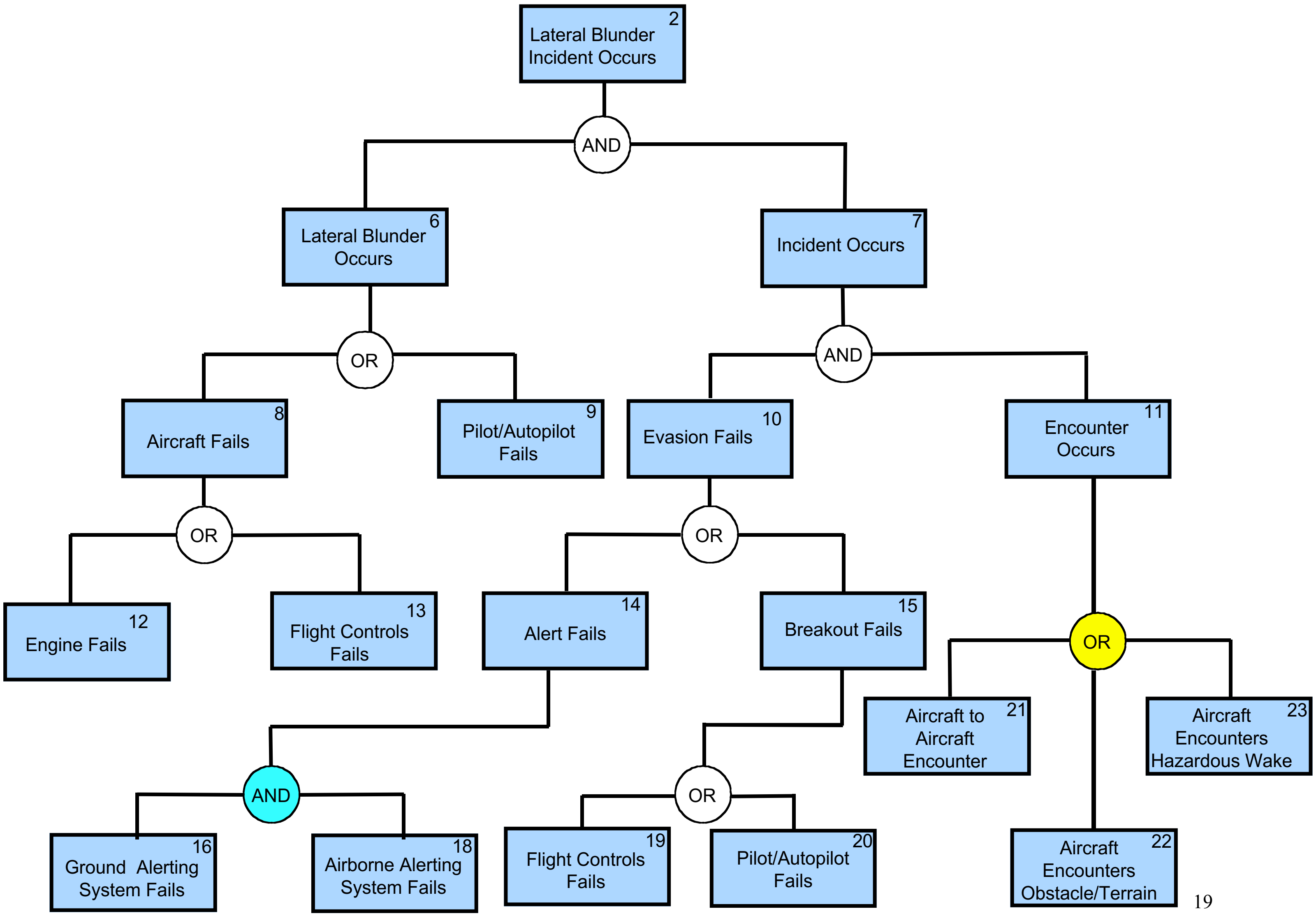
[1]**Jonathan Hammer CASE STUDY OF PAIRED APPROACH PROCEDURE TO CLOSELY SPACED PARALLEL RUNWAYS ,** Air Traffic Control Quarterly, Vol. 8(3) 223.252 (2000)

TACEC Lateral Blunder Scenario



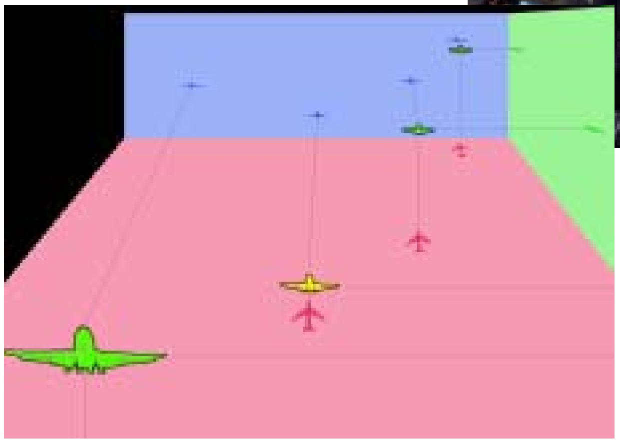
TACEC Lateral Blunder Scenario Fault Trees

Raytheon
Network Centric Systems



Human Performance

- Ongoing effort to address the role of human operator in TACEC
- Focus on cockpit visualization to achieve all weather closely spaced parallel approaches
- Experiment planned for 2004 to evaluate alternative visualizations



Performance results and Lessons learned

- **Flight corridors define a wake vortex hazard free region:**
  - **Lower limit**
    - » **Final approach lateral spacing of 500 feet**
    - » **Time difference on final less than 30 seconds**
  - **Crosswind impact on lateral spacing (RCL spacing)**

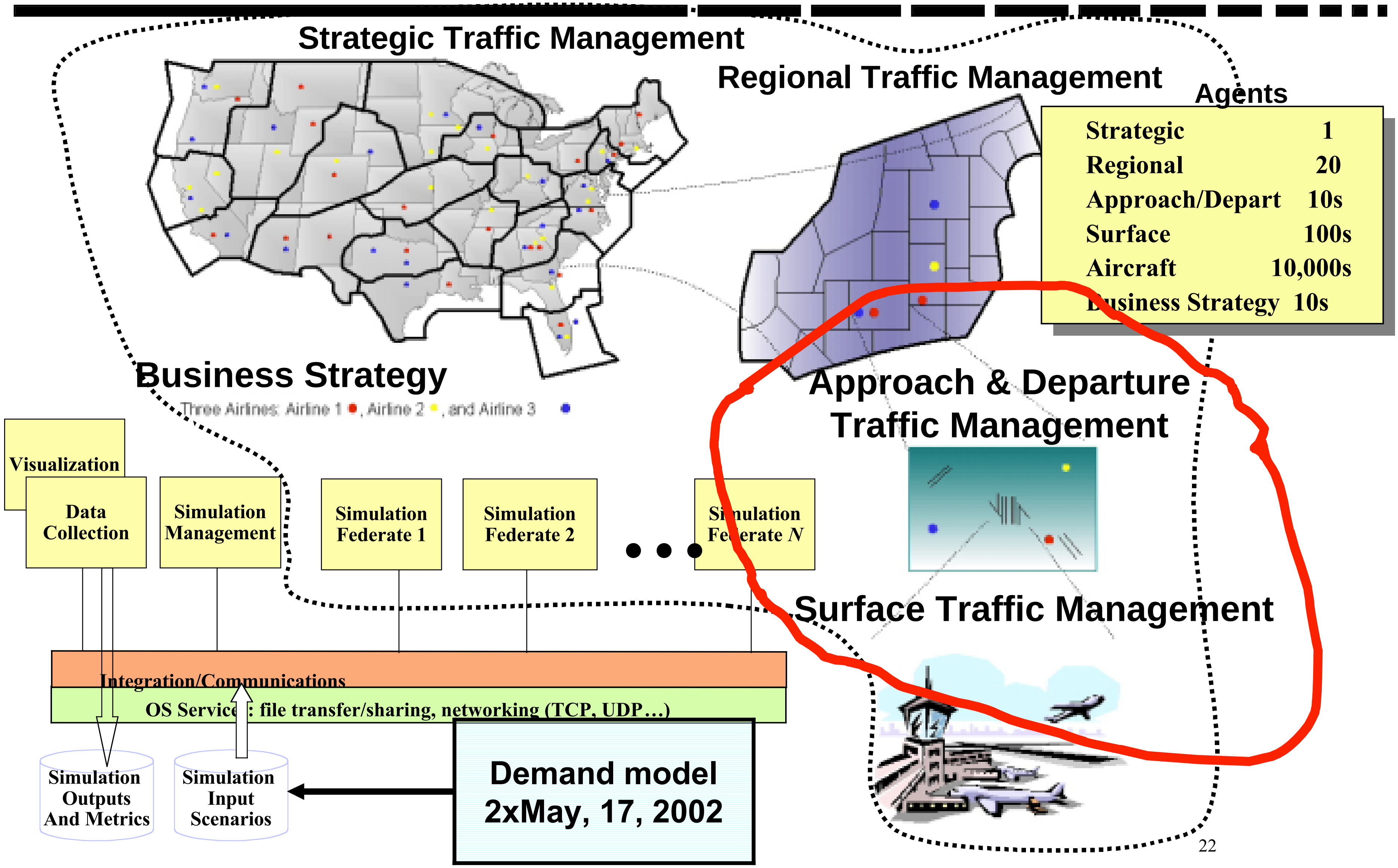
t_{Δ}	10 knot	20 knot	30 knot
10 sec	650ft	800ft	950ft
20 sec	800ft	1100ft	1400ft
30 sec	1000ft	1400ft	1800ft

- **Aircraft position must be controlled within 10 meters to achieve 10 seconds between aircraft**

  - FTE must be improved by an order of magnitude

NAS-wide Assessment using ACES

Raytheon Network Centric Systems



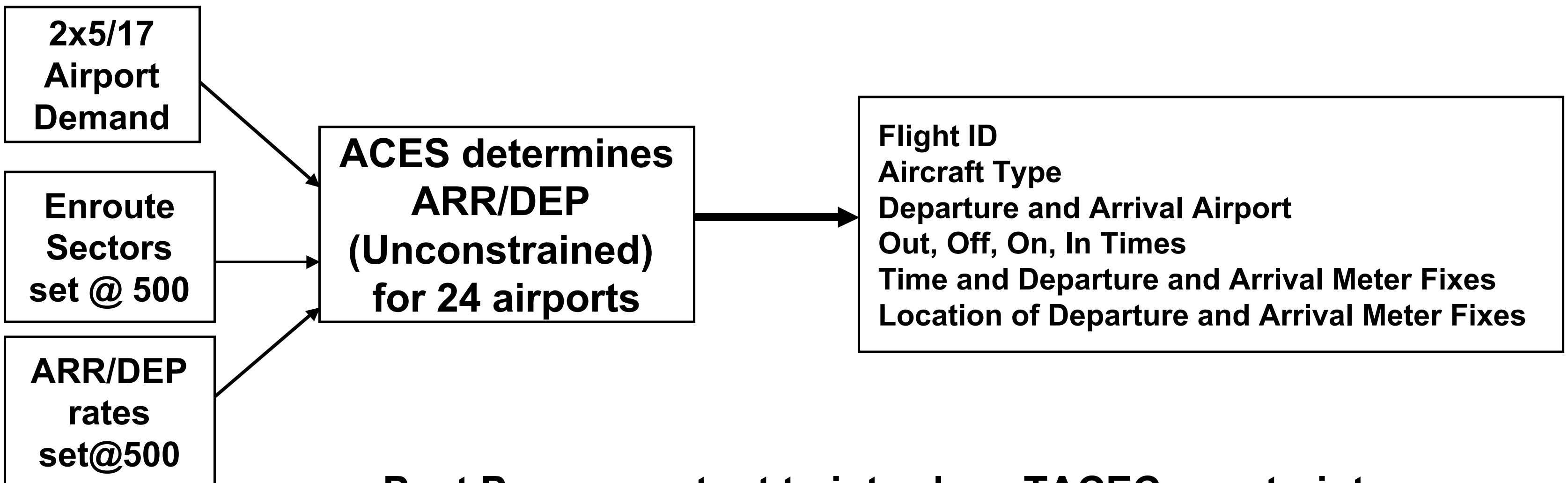
Evaluation Metrics

Raytheon
Network Centric Systems

Metric	Derivation
Block Time	(Actual Gate In) – (Scheduled Gate Out)
Delta Block Time	(Benchmark[1] Block Time) – (Evaluation Case Block Time)
Total Delta Block Time	Sum of Block Time Delta
Potential Capacity Increase	# of flights arriving(departing) # of arriving(departing) groups
Delay	Delta Block Time

[1]The Benchmark Scenario in the individual airport analysis was the Worst Case (Baseline Sector/Baseline Airport) scenario, while in the NAS-wide analysis it was the Ideal (Sector 200/Airport 200) scenario.

NAS-wide Assessment using ACES - Individual Airport Assessment



Post Process output to introduce TACEC constraints:

1. Grouping a/c by performance
2. Time of arrival at Entry Fix
3. Entry fix direction wrt to runway
4. Number of aircraft in group

NAS-wide Assessment using ACES - Individual Airport Assessment

Raytheon
Network Centric Systems

- Criteria for determining an airports TACEC arrival capacity;
  1. **they have the same weight descent category**
  2. **and they arrive within delta seconds of each other**
  3. **and the angle between their arrival fix and the runway direction is both within 90 degrees, or they are both not within 90 degrees**

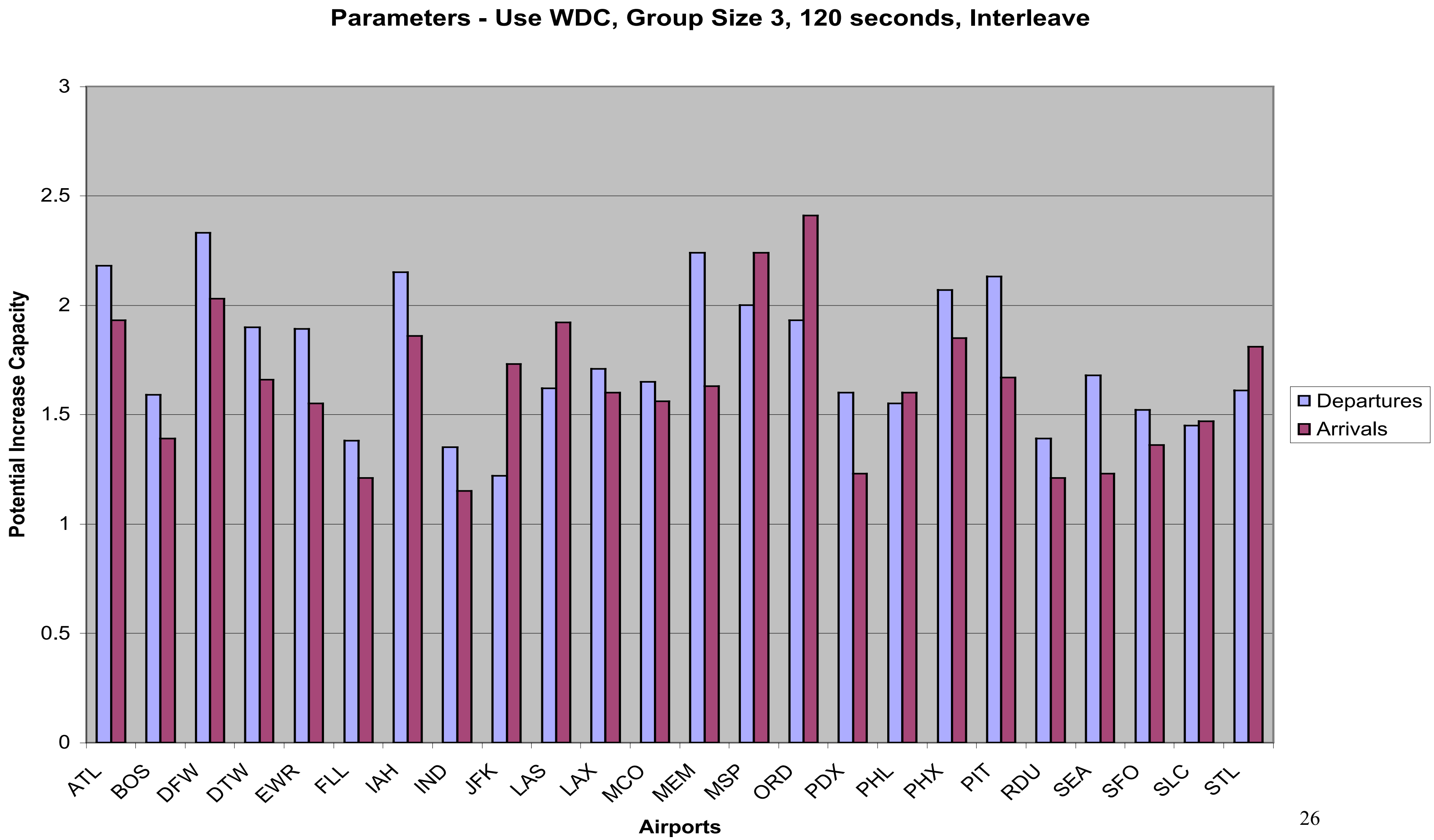
Total number of flights (24 hours)	824
Considered time interval [hr]	1
Grouping interval [s]	120
Ignore WDC	FALSE
Interleave	TRUE
Runway Configuration [deg]	90
Maximum Group Size	3
Airport EWR	
Number of AC (busiest hour)	73
Number of Groups	47

Group	Flight ID	ACID	A/C Type	WTC	OnTime	ArrivalFix
1	1127_1146	USA1053	B733	L2	7:25:10 PM	NW
2	224_225	AAL1698	MD80	L1	7:25:19 PM	NW
2	1125_1144	BTA3495	E145	L1	7:25:51 PM	NW
2	1129_1148	BTA3406	E145	L1	7:26:06 PM	NW
3	1100_1119	COA1783	B733	L2	7:27:47 PM	SW
4	1107_1126	TRS574	DC9	L1	7:28:21 PM	SW
5	147_148	COA1580	B738	L2	7:30:29 PM	NW
5	155_156	COA1049	B737	L2	7:31:35 PM	NW
6	1141_1160	BTA4048	E145	L1	7:30:35 PM	SW

NAS-wide Assessment using ACES - Individual Airport Assessment

Raytheon
Network Centric Systems

TACEC capacity increase potential at the 24 selected airports

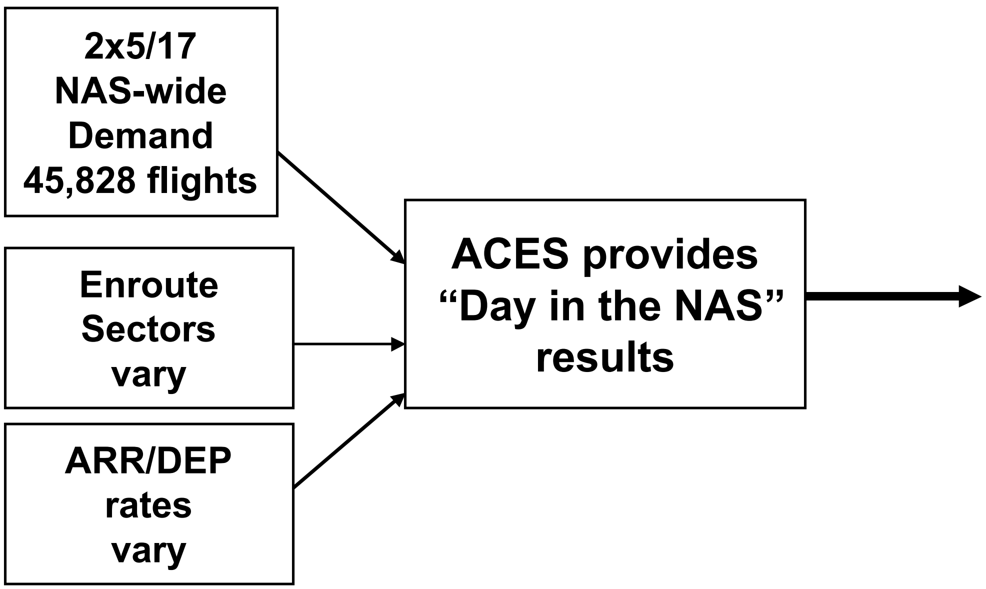


NAS-wide Assessment using ACES - Individual Airport Assessment

Raytheon
Network Centric Systems

TACEC capacity increase reflects the airport's demand…..

NAS-wide Assessment using ACES



- The Baseline Sector/Baseline Airport will be evaluated to determine the Worst-case delay

- The sectors will be held fixed at baseline capacities, and the airport adjusted to the nominal TACEC case (Use WDC, Size 3)

- The sectors will be set to 200 and the airports set back to baseline.

- The sectors will be set to 200 and the airports adjusted to the nominal TACEC Case.

- A comparison of runs 3 & 4 will establish the delay reduction produced by TACEC.

- The sectors will be set to 200 and TACEC will be adjusted to Use WDC, Size 2

- The sectors will be set to 200 and TACEC will be adjusted to Ignore WDC, Size 3

NAS-wide Assessment using ACES

Raytheon
Network Centric Systems

Airport Capacity

Sector Capacity	Baseline	TACEC
Baseline	1) Baseline/Baseline	1) Baseline Sectors, TACEC=Use WDC, Group Size 3
200	1) Sectors=200, Baseline Airport	1) Sectors=200, TACEC=Use WDC, Group Size 2 2) Sectors=200, TACEC=Use WDC, Group Size 3 3) Sectors=200,TACEC=Ignore WDC, Group Size 3

NAS-wide Assessment using ACES

Raytheon
Network Centric Systems

- **Block Time results for 3 a/c group**

	Ideal, Sector & Airport 200	Scenario A, Base Sector, Base Airport	Scenario B, Base Sector, TACEC Airport	Scenario C, Sector 200, Base Airport	Scenario D, Sector 200, TACEC Airport
Total Block Time (Hrs)	86245	134109	121135	115505	93311
% Block Time Increase		0.55	0.40	0.34	0.08

- **Block Time results for 2 or 3 a/c group**

	Ideal, Sector & Airport 200	Sector 200, Use WDC & Size 2	Sector 200, Use WDC & Size 3	Sector 200, Ignore WDC & Size 3
Total Block Time (Hrs)	86245	93559	93311	93337
% Block Time Increase		0.08	0.08	0.08

NAS-wide Assessment using ACES - Results and lessons learned

- Comparing the "ideal" across the scenarios……...

	Ideal, Sector & Airport 200	Sector 200, Use WDC & Size 2	Sector 200, Use WDC & Size 3	Sector 200, Ignore WDC & Size 3
Total Block Time (Hrs)	86245	93559	93311	93337
% Block Time Increase		0.08	0.08	0.08

	Scenario A, Base Sector, Base Airport	Scenario B, Base Sector, TACEC Airport	Scenario C, Sector 200, Base Airport	Scenario D, Sector 200, TACEC Airport
Delay (Hrs)				
Total	47864	34890	29261	7067
Min	0	0	0	0
Max	28.74	25.27	14.9	10.35
Average	1.04	0.76	0.64	0.15

- **TACEC can provide;**
  - **92% of the ideal NAS**
  - **41,000 hrs less delay than OEP**
- **ARR/DEP groupings of 2 or 3 aircraft provide similar performance**
- **Demand drives results, May 17th is not sufficient to drive conclusions**

How the results further the concept description

- **Crosswinds**
  - The ability for three or more aircraft to use 500 ft RCL spacing is eliminated with crosswinds >10mph.
  - By controlling in trail spacing to within 10 secs, RCL spacing < 1,000 is possible for 3 or more aircraft.

- **Aircraft Position**
  - Flight Technical Error (FTE) will limit the ability of up-linked 4D trajectories to achieve space/time position. Certification of more accurate Flight Control Systems is required.

- **Capacity Gains for 2 or 3 aircraft grouping is similar**
  - Need significantly more demand "scenarios" to assess the need for more than 2 closely spaced runways.

Challenges

Raytheon
Network Centric Systems

- Data analysis using ACES
  - visualization tools needed
- Terminal area fidelity in ACES
  - Build 3 needed to assess impact of airport surface, terminal airspace trajectories, and complex geometry
- Wake Vortex characteristics and analysis
  - better fidelity vs time
  - establishment of “safe” vortex encounter
- Safety
- Human Factors