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Requirements for a Novel Terminal Area Capacity Enhancement Concept in 2022

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I. Abstract

A primary constraint on the capacity of the National Airspace System capacity is the arrival and departure rates at our major hub airports. Raytheon has developed a novel concept for terminal area operations that significantly increases arrivals and departures. The Terminal Area Capacity Enhancing Concept (TACEC) can double the number of aircraft arriving and departing by allowing very closely spaced parallel runway usage coupled with a unique wake vortex avoidance solution. Ongoing development efforts have included a NAS wide simulation to evaluate the potential capacity increases that TACEC can provide, as well as the feasibility of implementation at the nation's busiest airports. In addition an analysis of the terminal airspace performance requirements for aircraft and ATM operations provides the basis for a technology roadmap exercise that delineates the necessary developments for implementation by 2022. Finally an ongoing safety analysis provides an evaluation of the operational risks.

II. Introduction

Raytheon's Terminal Area Capacity Enhancing Concept (TACEC) focuses on the primary bottleneck of today's National Airspace System (NAS). Our domain of study includes today's TRACON airspace, airport operations and the airport(s) surface. The fundamental goal of TACEC is to significantly increase the capacity of the major airports in today's NAS. Based on modeling and analysis activities last year we have determined that the principal driver of Terminal area capacity is;

1. the availability of runways, and
2. wake vortex avoidance which sets the arrival/departure rate for the available runways.

TACEC addresses these capacity constraints using three Core Ideas; namely Flight Corridors, Staged 4D Trajectories and LAAS enabled Autoland coupled with Surface Traffic Management.

Flight Corridors minimizes the in trail separation used to avoid wake vortex hazards

TACEC addresses this fundamental capacity constraint by using individual flight corridors for wake avoidance. Flight corridors are defined flight path boundaries free of any wake vortex hazard. Corridors take advantage of the well-defined wake vortex characteristics near the generating aircraft, before winds and other effects create uncertainty in the vortex location. Because flight corridors are close in both time and distance to the lead aircraft, they also define approach paths that feed parallel runways. The close spacing required ensuring wake free regions lead to very closely spaced parallel runways.

Staged 4D Trajectories optimizes aircraft flight paths through the terminal airspace

The ability to maneuver aircraft entering the terminal airspace into the tightly spaced/timed final approach fixes defined by the Flight Corridors is a key element of TACEC. Conflict free 4D trajectories must be provided to all aircraft entering the terminal airspace, and since the environment will be changing, updates to these trajectories will be required. For this reason a secure, reliable data link must be used to provide this information.

CAT3 LAAS Enabled Autoland/Surface Management

To insure safe operation in closely spaced parallel approaches, the use of a LAAS based CAT-3 auto land is required for all aircraft in all weather conditions. Similarly the need to move aircraft from/to the runway thresholds is also key to achieving maximum capacity.

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III. TACEC Overview

TACEC is focused on increasing the capacity of terminal airspace (TRACONs in today's NAS) and it's associated airports. To accomplish significant increases in capacity requires fundamental changes to current operations. As previously described Raytheon addresses the primary constraints in terminal operations - wake vortex hazard avoidance and runway availability, with a novel approach based on Flight Corridors[1].

The TACEC approach to wake hazard avoidance reduces the uncertainties of hazardous wake location that today requires in trail separation. Instead of positioning the following aircraft far enough behind the lead aircraft such that the wake is dissipated, TACEC positions the following aircraft as close as possible to the lead aircraft. This guarantees a wake free region and eliminates the uncertainties introduced by winds, etc. Figure III-1 illustrates a multiple aircraft approach where hazard free regions are assured by maintaining latitudinal position offsets and a maximum time (or in trail longitudinal) separation. The key difference between this concept and current parallel runway implementations is the fact that TACEC minimizes in trail separation (▤t) to reduce wake vortex hazards instead of increasing separation to accommodate uncertainties. This principal can be applied to both arrivals and departures. Each wave of arrivals/departures will continue to be separated in trail to allow the dissipation of hazardous wake vortices generated by the leading group of aircraft.

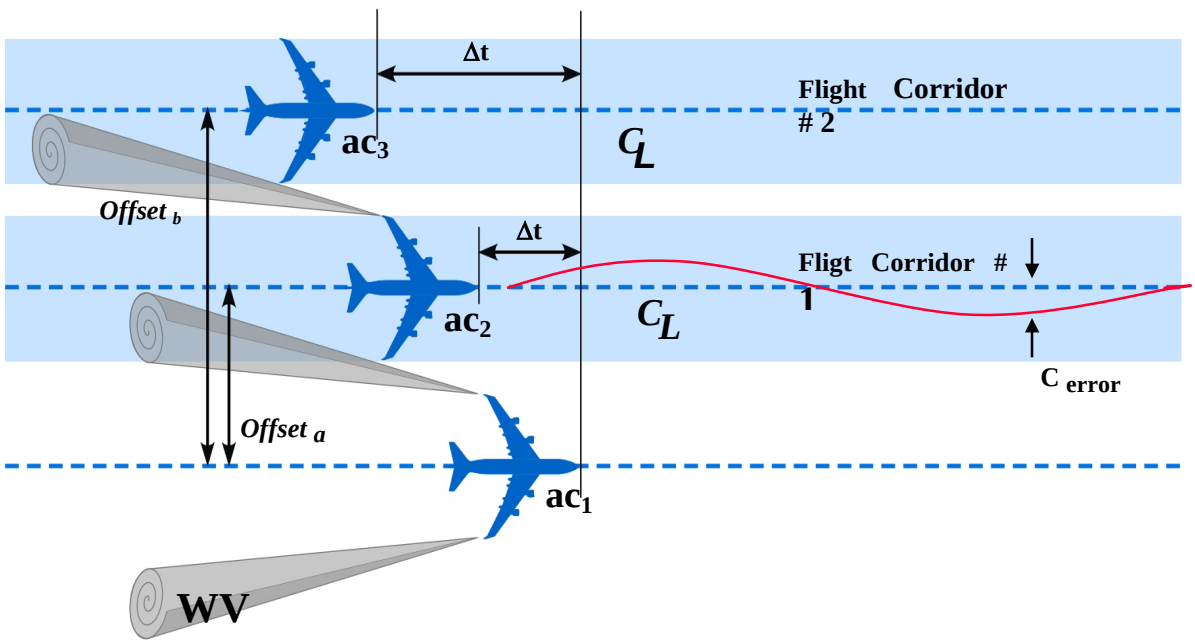


Figure III-1
TACEC Wake Hazard Avoidance Concept

A natural consequence of this wake avoidance approach is the ability to use very closely spaced parallel approaches/runways. This addresses the other fundamental constraint on capacity, namely the number of usable runways at the airport. Today an all-weather, independent parallel runway pair must be separated by 4300ft. This can be reduced by using a Parallel Runway Monitor (PRM) system to 2500 ft, but the use of closer spaced runways typically require visual meteorological conditions. More runways could be made available immediately if the current restrictions could be alleviated.

A key challenge to implementing TACEC is the ability to stage aircraft within the terminal airspace. As shown in Figure 2-2 the flight paths from entry into the terminal area must be controlled such that the candidate aircraft for closely spaced parallel approach hit the Final Approach Fix within the tolerable time and position required.

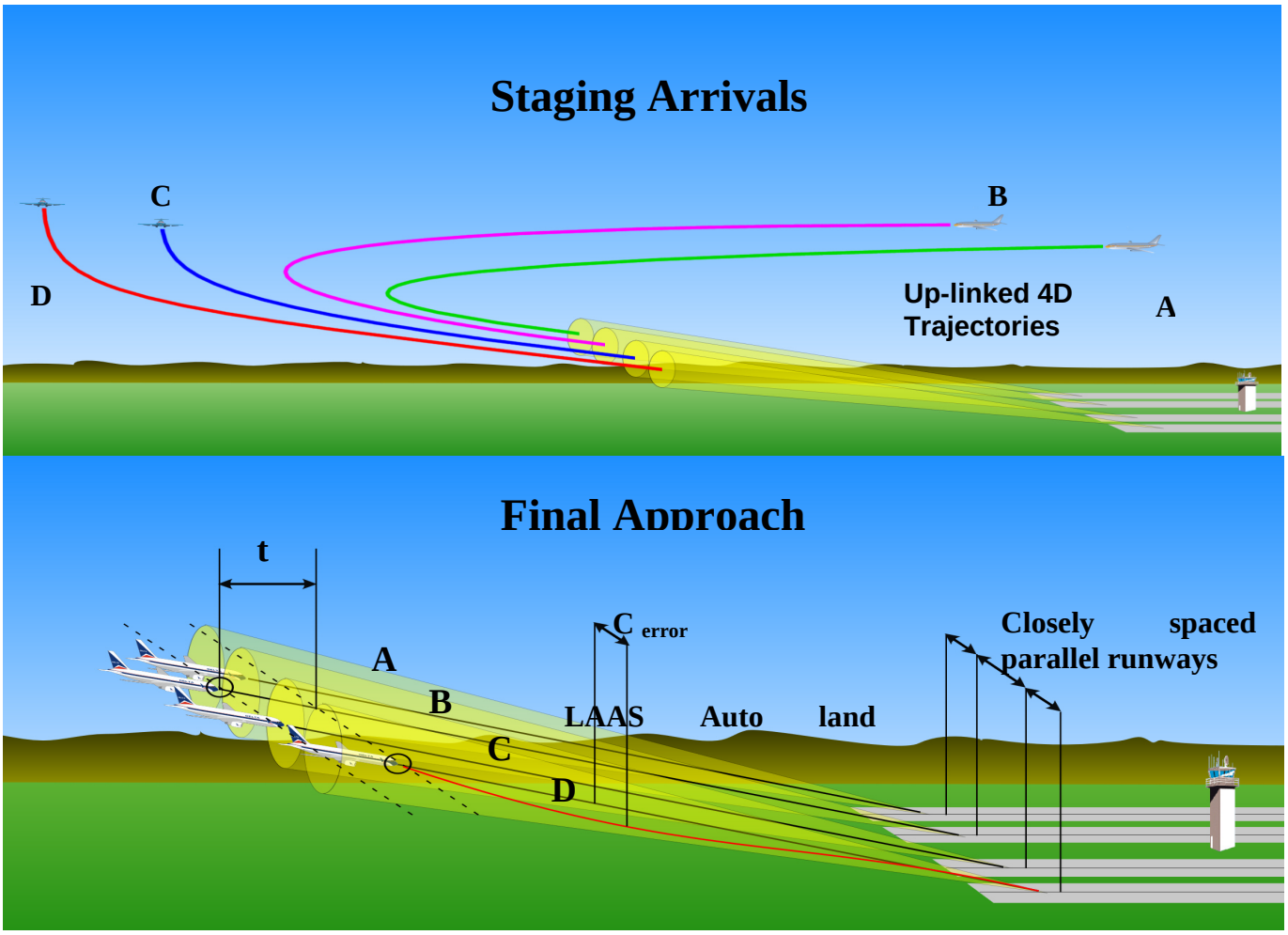


Figure III-2
Terminal Area Operation

Eliminating vortex hazards by minimizing the time and lateral difference between aircraft requires accurate flight control. It is envisioned that this will be accomplished by using differential GPS landing aids in conjunction with auto-land avionics with higher accuracy than ILS CAT3 performance achieved today. This capability will allow all weather operation and has the ability to fly approach paths within meter level accuracy.

The usable capacity of any airport will also be dependent on the efficiency of movement on the ground. All vehicles that share the airport surface must be routed to and from their origin/destination in the shortest time possible. Advanced Surface Traffic Management (STM) solutions are being investigated under the VAMS activity with similar goals to enhance airport capacity. TACEC intends to take advantage of this work in the next Phase to identify any surface movement limitations that arise with our closely spaced parallel runway approach.

TACEC can be viewed as an evolutionary approach to terminal area capacity improvements. As the technology advances to allow safe, closely spaced final approach operations in all weather conditions, existing airports with runway centerline spacing less than 4300ft can begin using TACEC operation.

As demand increases at the candidate airports shown above, infrastructure improvements coupled with aircraft equipage could be planned for more parallel runway operations. Safe, all weather autoland operations can be established at 3000-4000 ft runway separations using LAAS technology and improved flight control avionics. Operational experience can then allow migration to closer runways, and the economic benefits to airline operations demonstrated for further investment in avionics. New runway construction can be planned as well. The ability to add runways is significantly improved if they can be built on existing airport land. If parallel runway spacing could be reduced to 750 ft a number of the country's busiest airports could add new runways between existing runways.

IV. Performance Drivers

There are three key factors that establish the viability of TACEC and its ability to significantly increase capacity. Section V discusses how we modeled these factors; the following describes them and their contribution to the overall TACEC performance.

Aircraft Position The positional relationship between aircraft in the terminal airspace is a primary performance driver. TACEC requires a very stringent 4 dimensional relationship between all participating aircraft. Controlling the aircraft's position and knowing where the aircraft is at any time is key to TACEC operations. Position is established by a number of factors, including;

- Aircraft Performance – the ability of the aircraft to fly a specific 4D route, in the appropriate phase of flight. This determines its ability to achieve the desired flight profile TACEC needs to both stage the aircraft for final approach and to fly the very closely spaced parallel landing.
- Position Verification Integrity – The ability for both the flight crew and the ground operation to know where the aircraft is located at any point in time and the assurance provided by independent assessments is critical.
- Operating environment – The wind, visibility, atmospheric conditions, etc will have an impact on actual aircraft location
- Flight Technical Error – TACEC uses FMS controlled 4D trajectories for terminal airspace operation and LAAS Autoland operation for landing operation. The inability of the aircraft flight control systems to comply with the computed flight profiles will result in a deviation from the desired path. Even though GPS (and in the case of LAAS Differential GPS) can provide highly accurate positional solutions, there will always be an error induced by the operating environment, onboard control systems, and aerodynamic properties. Future automated flight control solutions will alleviate some of this error, but adoption by the stakeholders will be driven by economic factors.

The most important impact of aircraft positioning on TACEC operation is the ability to maintain final approach positioning between descending aircraft. As discussed below TACEC depends on closely spaced parallel approaches to insure wake vortex hazard avoidance, as well as the opportunity to use closely spaced parallel runways.

Two or more aircraft must be flown both laterally and longitudinally within a tight tolerance to achieve the

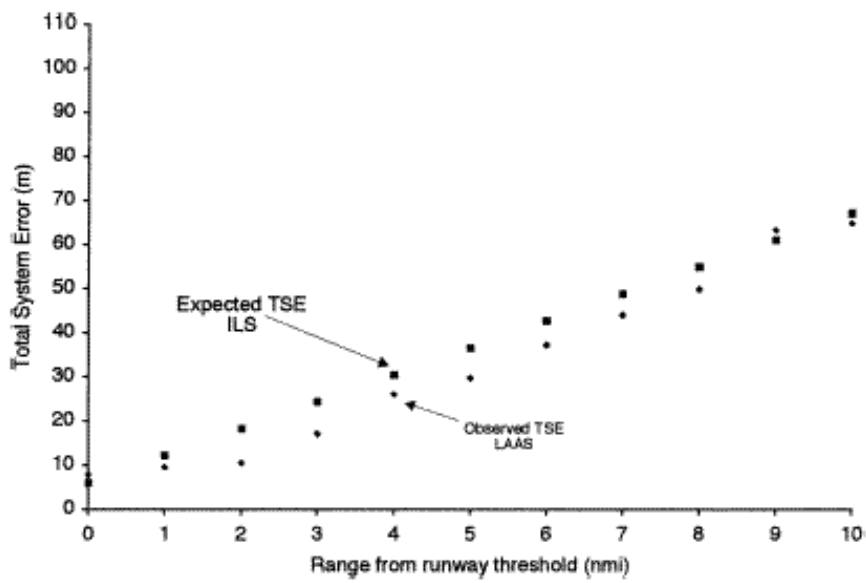


Figure IV-1
ILS/LAAS Total System Errors

capacity benefits offered by the TACEC operation. At the same time precise control over position is necessary to insure safe operation and avoid blunders during final approach operations. The use of differential GPS landing systems can provide highly accurate approach guidance, independent of range like today's ILS. However the flight

path error in such automated systems includes more than the navigation errors. Total System Error (TSE) includes the errors contributed by flight control systems (Flight Technical Error – FTE.) Studies done at Mitre, with help from the FAA Tech Center[2] have shown that today's avionics provide very similar TSE whether using current ILS landing aids or future LAAS DGPS systems. (See Figure IV-1.) This is primarily because LAAS receivers are designed to interface with ILS based flight control solutions on today's aircraft. TACEC is envisioned to operate with flight control avionics that provide significantly better accuracy, hence reducing errors by an order of magnitude, commensurate with the GPS navigational accuracy performance.

A key aspect of aircraft positioning on final approach is the aircraft performance, including the type of aircraft, gross weight, and the operating environment. In addition on final there is an inherent speed difference resulting from aircraft beginning their speed reduction for descent at different times. Differing descent speeds will result in a longitudinal separation that changes over time and will impact the necessary position relationship needed for wake hazard avoidance.

.As discussed in the following section, it is necessary to maintain close position and time differentials between aircraft on final approach for wake hazard avoidance. Once again the ability to achieve accurate 4D flight profiles, especially on final approach, will require advanced flight control avionics. TACEC will require Flight Technical Errors in the realm of meters, resulting in speed control accuracy of less than 10 mph, hence time differences along the final approach path of less than 10 seconds.

Wake Vortex Avoidance – The hazards of wake vortex are well known. Current FAA operations are based on avoiding any flight path that would intercept a wake vortex, no matter what its strength or roll inducing moment and wake avoidance is based on the fact that the wake will dissipate over time. The FAA Technical Order 7110.65M establishes wake hazard mitigation procedures for ATC operations by separating aircraft a minimum distance. This separation is based on the wake vortex generating characteristics of the lead aircraft and the size of the trailing aircraft. Table 2-1 is the current separation required between a following aircraft and the various types of aircraft.

Following Aircraft Gap, (nm)	Lead Aircraft			
	Small	Large	B757	Heavy
Small	2.5	4	5	6
Large	2.5	2.5	4	5
Heavy	2.5	2.5	4	4

Table IV-1
Wake Mitigation Separation

TACEC deals with wake hazards by utilizing the concept of Flight Corridors wherein a dynamic, hazard free region is continuously determined in the region behind a leading aircraft. In order to establish the corridor, wind and self induced wake dynamics are used to establish a non-hazardous region. Figure IV-2 illustrates the contours of vortex induced roll moments generated on an aircraft wing. The cross-hatched region around the vortex centers indicate where a following aircraft would experience over–powering rolling moments from the vortex generated by the lead aircraft. The "boundary" is based primarily on the wing span of the both leading and following aircraft initially, and then expands as a function of time due to self induced dispersion and atmospheric effects.

This approach to wake hazard avoidance differs from today's operations in that it recognizes a hazardous spatial region to avoid, as opposed to today's attempt to avoid any possibility of flying in a wake perturbed airspace. Consequentially the confidence in predicting wake hazard regions must approach 100%, requiring new means to assess the various contributors to vortex generation and characteristics. Flight corridors envision that onboard wind measurements will be a key factor in predicting accurate wake transport vs. time and that analytical wake predictions will be improved through the use of accumulated measurements using today's evolving wake sensing technologies such as LIDAR. In addition on site wake, wind and atmospheric data is required to continuously update the current wake hazard characteristics.

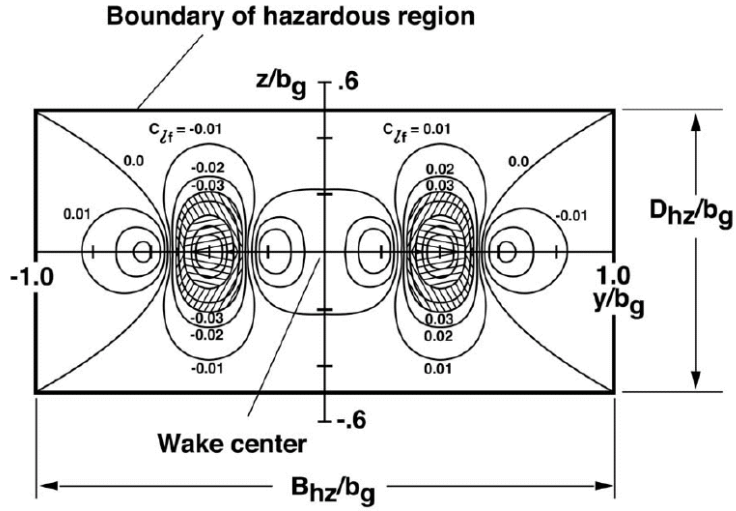


Figure IV-2
Hazardous Wake Characteristics

TACEC refines the Flight Corridor approach by requiring aircraft to fly in the region where wake hazards are most deterministic, namely in close proximity to the lead aircraft. The initial wake characteristics are determined by the generating aircraft's wing span, the hazardous region is a function of the trailing aircraft's wing span. From Rossow[3] the Breadth and Depth of the initial hazardous wake to a relatively small following aircraft is given by

$B_{hz}(t) \sim 2b_g$ where B_{hz} = Breadth of the Hazardous Region and
b_g = wing span of the generating aircraft

$D_{hz}(t) \sim b_g$ where D_{hz} = Depth of the Hazardous Region

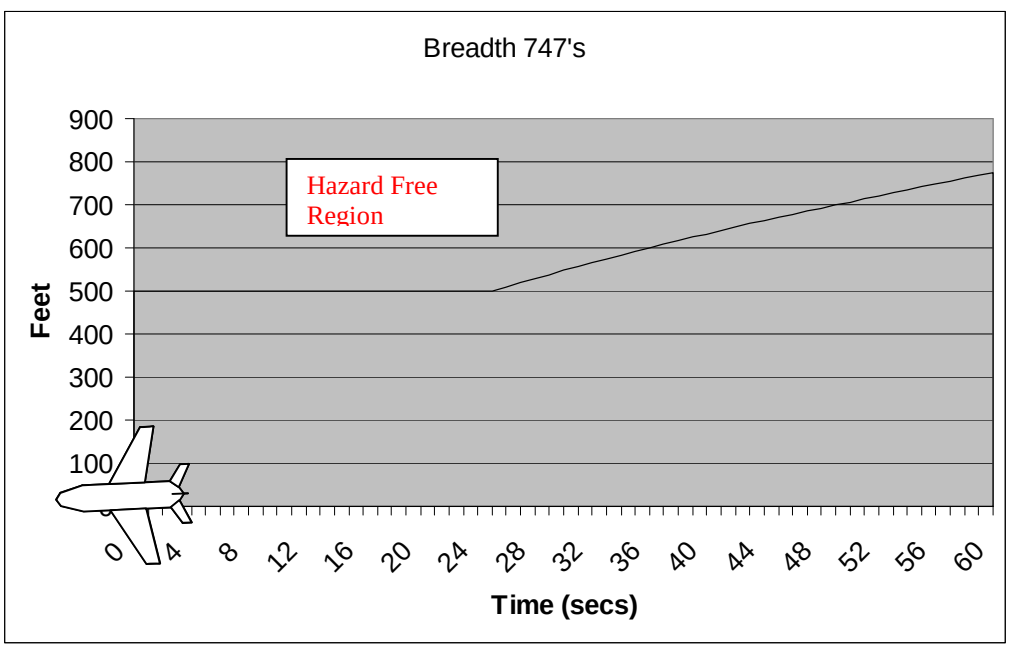
While for aircraft of similar size the breadth becomes;

$B_{hz}(t) \sim 2.5b_g$ to reflect the larger wingspan of the following aircraft.

The wake begins to enlarge over time, and can be represented by the relationship;

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

However the initial breadth and depth set by wing span dominates until the value of 2 to 2.5 b_g is exceeded.



Hazardous Wake Regions for 747 aircraft
Figure IV-3

Figure IV-3 illustrates the hazardous region expansion versus time for a 747 generating aircraft and a 747 follower. (Note that 0 feet is the centerline of the wake generating aircraft and time=0 would be the case where the two aircraft are exactly side by side on a parallel approach path.)

Figure IV-3 shows that two 747's could fly with a lateral separation as small as 500 ft, as long as they were displaced in time by less than 25 seconds. As the trailing aircraft drifts further behind the wake generating aircraft the hazardous region spreads out, requiring additional lateral separation.

In addition to the self-induced spreading, wake vortices are effected by wind. Cross winds will accelerate the wake spreading, in direct proportion to the wind velocity. Accommodating cross winds will require aircraft positioning such that the down wind aircraft always leads the trailing aircraft, imposing tighter positioning requirements on approaching aircraft.

Safety Issues and Human Operations - TACEC's ability to improve NAS capacity must not compromise the safety of today's operations. With the large increase in daily flight operations envisioned for 2022, it is necessary to improve safety to insure accident rates do not increase linearly with the traffic density. As discussed previously, the key features of TACEC require aircraft to fly significantly closer together during final approach, requiring highly accurate automated flight control.

As a first step in evaluating the safety of operations a Fault Tree Analysis was developed to assess the probability of collision or wake encounters due to blunders. Two types of blunders were chosen, lateral and in trail (longitudinal) errors. Figure IV-4 and IV-5 illustrates the problems.

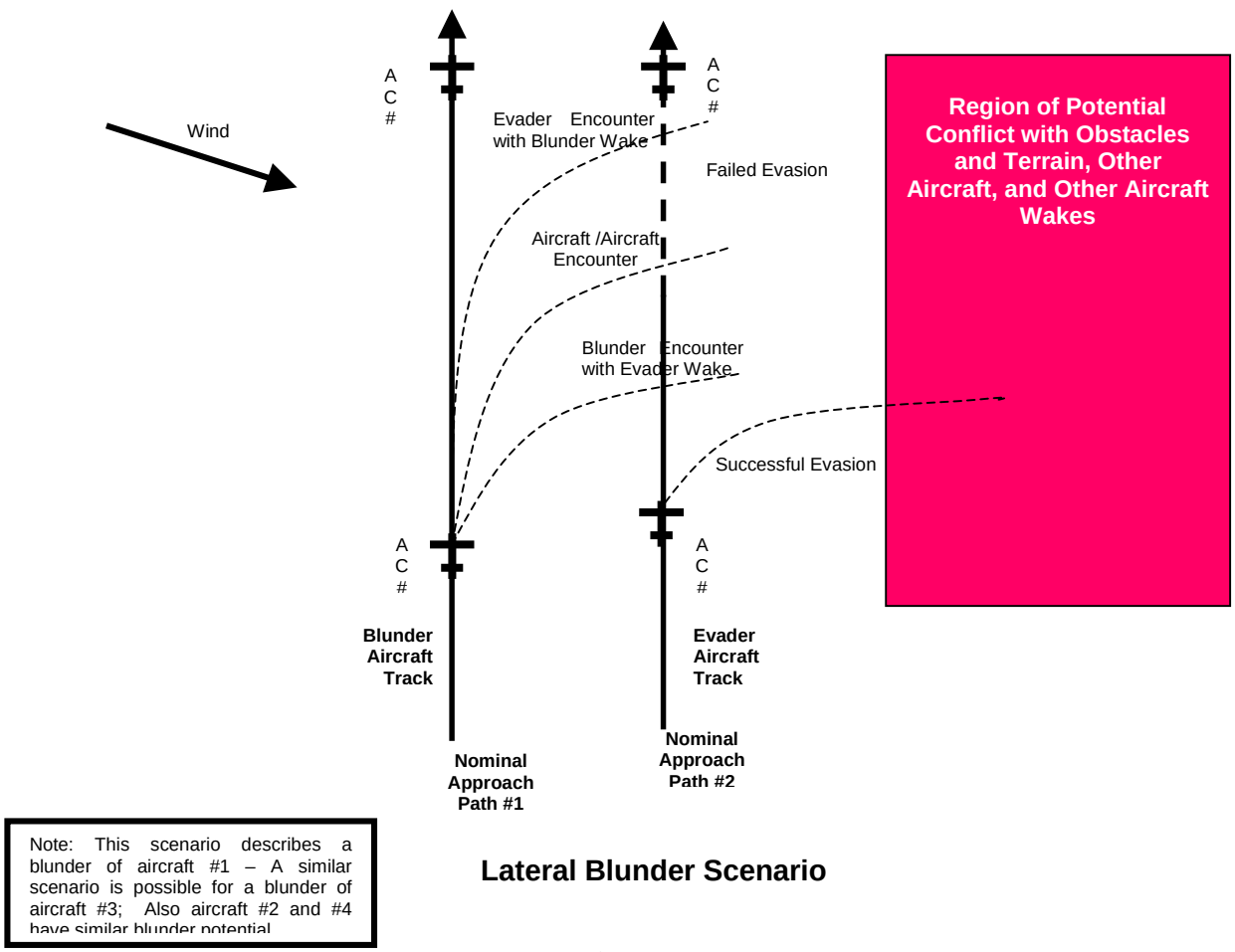
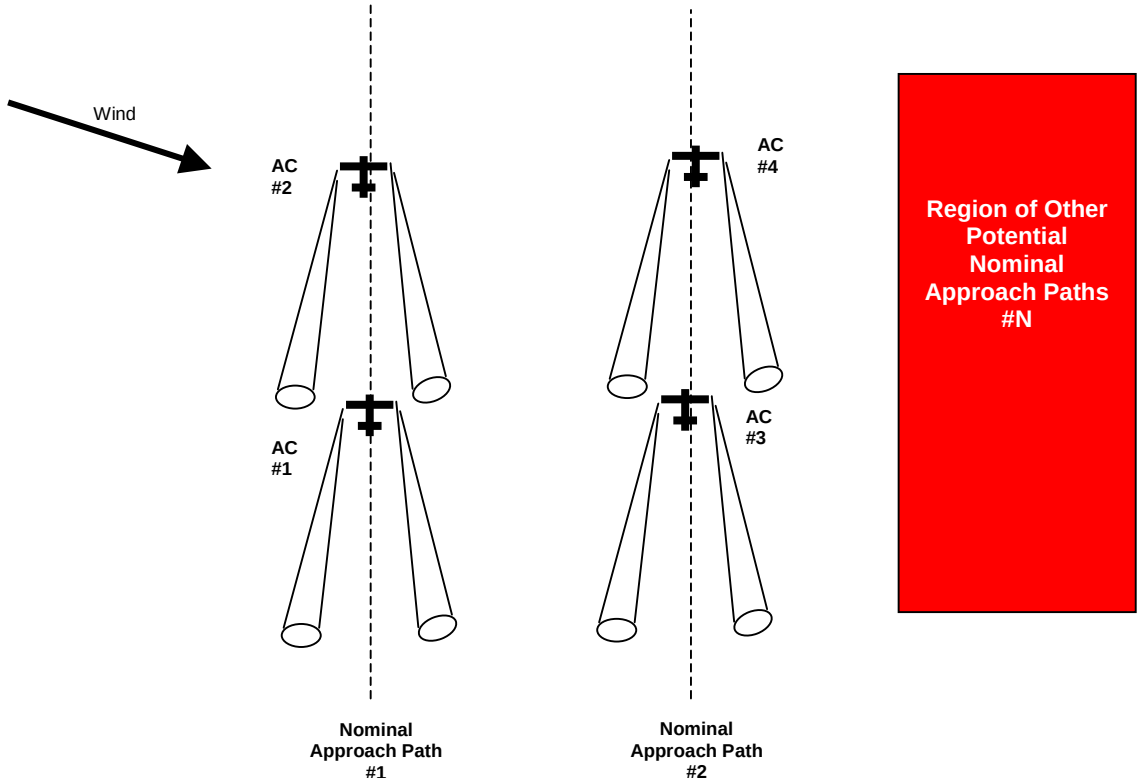


Figure IV-4



Longitudinal Blunder Scenario

Figure IV-5

Initial results used an "educated guess" for the probabilities of each element of the fault tree and an assessment of the probability of an incident was calculated. Further effort is planned to conduct a sensitivity analysis to isolate key contributors to potential blunders. Table IV-2 summarizes the initial results for TACEC and Baseline (today's) operation.

Input Probabilities (Baseline)	Value	Input Probabilities (TACEC)	Value
(set to zero)	0.000000E+00	Pilot error (e.g., override)	1.000000E-07
AC Supporting Equipment Fails	1.000000E-09	AC Supporting Equipment Fails	1.000000E-09
AC Control System Fails	1.000000E-09	TACEC Control System Fails	1.000000E-09
Pilot fails to detect blunder	1.000000E-07	TACEC Airborne blunder alerting system misses valid alert	1.000000E-09
(set to zero)	0.000000E+00	TACEC Airborne blunder alerting system not timely	1.000000E-09
PRM misses valid blunder alert	1.000000E-09	TACEC misses valid blunder alert	1.000000E-09
ATC communications fails	1.000000E-09	TACEC uplink fails tp provide timely alert	1.000000E-09
ATC fails to provide timely blunder alert	1.000000E-07	TACEC fails to provide timely blunder alert	1.000000E-09
AC control system fails	1.000000E-09	AC control system fails	1.000000E-09
PRM system causes false alert	1.000000E-09	TACEC ground based evasion alerting system issues false alert	1.000000E-09
(set to zero)	0.000000E+00	TACEC ground based blunder alerting system issues false alert	1.000000E-09
(set to zero)	0.000000E+00	TACEC airborne evasion alerting system issues false alert	1.000000E-09
Pilot detects false alert	1.000000E-07	TACEC airborne blunder alerting system issues false alert	1.000000E-09
Pilot error (e.g., over ride)	1.000000E-07	Pilot error (e.g., over ride)	1.000000E-07
AC supporting equipment fails	1.000000E-09	AC supporting equipment fails	1.000000E-09
Autoland system fails	1.000000E-09	Autoland system fails	1.000000E-09
Critical AC system fails on final approach	1.000000E-09	Critical AC system fails on final approach	1.000000E-09
Blunder AC encounters OT(Set Pr = 0)	0.000000E+00	Blunder AC encounters OT (Set Pr = 0)	0.000000E+00
Evader AC encounters OT(Set Pr = 0)	0.000000E+00	Evader AC encounters OT(Set Pr = 0)	0.000000E+00
Blunder AC encounters evader wake	2.870000E-07	Blunder AC encounters evader wake	0.000000E+00
Evader AC encounters blunder wake	2.870000E-07	Evader AC encounters blunder wake	2.870000E-07
Blunder AC encounters other wake(Set Pr = 0)	0.000000E+00	Blunder AC encounters other wake (Set Pr = 0)	0.000000E+00
Evader AC encounters other wake(Set Pr = 0)	0.000000E+00	Evader AC encounters other wake(Set Pr = 0)	0.000000E+00

Vortex strength > minimum value (SetPr = 1)	1.000000E+00	Vortex strength > minimum value (SetPr = 1)	1.000000E+00
Blunder AC encounters evader AC	0.000000E+00	Blunder AC encounters evader AC	0.000000E+00
Evader AC encounters other AC(Set Pr = 0)	0.000000E+00	Evader AC encounters other AC(Set Pr = 0)	0.000000E+00
Blunder AC encounters other AC(Set Pr = 0)	0.000000E+00	Blunder AC encounters other AC(Set Pr = 0)	0.000000E+00
(set to zero)	0.000000E+00	Pilot Error (e.g., over ride)	1.000000E-07
AC control system fails	1.000000E-09	TACEC control system fails	1.000000E-09
AC supporting equipment fails	1.000000E-09	AC supporting equipment fails	1.000000E-09
Pilot misses alert	1.000000E-07	TACEC airborne evasion alerting system misses valid alert	1.000000E-09
(set to zero)	0.000000E+00	TACEC airborne evasion alerting system not timely	1.000000E-09
Ground support equipment fails (e.g., power)	1.000000E-09	Ground support equipment fails (e.g., power)	1.000000E-09
ATC communications fails	1.000000E-09	TACEC uplink fails	1.000000E-09
Ground based PRM fails	1.000000E-09	Ground based TACEC fails	1.000000E-09
(set to zero)	0.000000E+00	TACEC fails to provide timely alert	1.000000E-09
Pilot fails to breakout safely given an alert	1.000000E-07	Pilot fails to breakout safely given an alert	1.000000E-07
Critical AC system fails on breakout	1.000000E-09	Critical AC system fails on breakout	1.000000E-09
Clearance communication error (ATC)	1.000000E-09	Clearance communication error (TACEC)	1.000000E-09
(set to zero)	0.000000E+00	Pilot error (e.g., over ride)	1.000000E-07
AC control system fails (ATC mode)	1.000000E-09	AC control system fails (TACEC mode)	1.000000E-09
AC flies into wake given failure to follow ATC clearance	1.000000E-07	AC flies into wake given failure to follow TACEC clearance	1.000000E-07
Faulty Met (e.g., wind) data	1.000000E-07	Faulty Met (e.g., wind) data	1.000000E-07
ATC fails to give timely clearance	1.000000E-07	TACEC DST fails to give timely clearance	1.000000E-09
ATC communications fails	1.000000E-09	TACEC uplink fails to provide timely clearance	1.000000E-09
Vortex strength > minimum value (SetPr = 1)	1.000000E+00	Vortex strength > minimum value (SetPr = 1)	1.000000E+00
AC flies into wake given untimely ATC clearance	1.000000E-07	AC flies into wake given untimely TACEC clearance	1.000000E-07

Output Probabilities (Baseline)	**Value**	**Output Probabilities (TACEC)**	**Value**
Pilot fails to respond to blunder	2.000000E-09	TACEC-pilot fails to respond to blunder alert	1.020000E-07
AC fails to respond to blunder	1.020000E-07	AC fails to receive timely airborne based blunder alert	1.040000E-07
AC fails to receive timely ground based blunder alert	1.020000E-07	AC fails to receive timely ground based blunder alert	3.000000E-09
Blunder alert fails	1.040400E-14	Blunder alert fails	3.120000E-16
Pilot does not take action to correct deviation	1.040400E-23	Pilot does not take action to correct deviation	3.120000E-25
Pilot responds to false alert	1.010000E-07	AC responds to false alert	4.000000E-09
Autoland fails to maintain flight path	1.020000E-07	Autoland fails to maintain flight path	1.020000E-07
AC deviates from the OK zone	2.040000E-07	AC deviates from the OK zone	1.070000E-07
Lateral Blunder Occurs	2.122416E-30	Lateral Blunder Occurs	3.338400E-32
AC to Obstacle/Terrain Incident	0.000000E+00	AC to Obstacle/Terrain Incident	0.000000E+00
AC encounters wake	5.739999E-07	AC encounters wake	2.870000E-07
AC to hazardous wake incident	5.739999E-07	AC to hazardous wake incident	2.870000E-07
AC to AC incident	0.000000E+00	AC to AC incident	0.000000E+00
Incident occurs given evasion fails	5.739999E-07	Incident occurs given evasion fails	2.870000E-07
Pilot fails to respond to valid alert	2.000000E-09	TACEC-pilot fails to respond to evasion alert	1.020000E-07
AC fails to receive timely airborne based evasion alert	1.020000E-07	AC fails to receive timely airborne based evasion alert	1.040000E-07
ATC fails to provide timely alsrt	2.000000E-09	TACEC uplink fails to provide timely alsrt	2.000000E-09
PRM system misses valid alert	2.000000E-09	TACEC ground based evasion alerting system misses valid alert	2.000000E-09
AC fails to receive timely ground based evasion alert	4.000000E-09	AC fails to receive timely ground based evasion alert	5.000000E-09
Evasion alert fails	1.060000E-07	Evasion alert fails	1.090000E-07
Breakout fails	1.010000E-07	Breakout fails	1.010000E-07
Evasion fails	2.070000E-07	Evasion fails	2.100000E-07
Lateral incident occurs given a blunder	1.188180E-13	Lateral incident occurs given a blunder	6.027000E-14
Lateral blunder incident occurs	2.521812E-43	Lateral blunder incident occurs	2.012054E-45
Pilot fails to follow ATC clearance	2.000000E-09	TACEC-pilot fails to follow TACEC clearance	1.020000E-07
Trailing AC flies into wake due to failure to follow clearance	2.000000E-16	Trailing AC flies into wake due to failure to follow clearance	1.020000E-14
AC fails to receive timely TACEC Clearance	2.010000E-07	AC fails to receive timely TACEC Clearance	1.020000E-07
Trailing AC flies into wake due to untimely clearance	2.010000E-14	Trailing AC flies into wake due to untimely clearance	1.020000E-14
Trailing AC flies into wake	2.030000E-14	Trailing AC flies into wake	2.040000E-14
AC1 vortex incident with AC2	2.030000E-14	AC1 vortex incident with AC2	2.040000E-14
AC1 vortex incident with AC3	2.030000E-14	AC1 vortex incident with AC3	2.040000E-14
AC1 vortex incident with AC4	2.030000E-14	AC1 vortex incident with AC4	2.040000E-14
Longitudinal blunder incident occurs	6.090000E-14	Longitudinal blunder incident occurs	6.120000E-14

In-trail incident occurs	2.436000E-13	In-trail incident occurs	2.448000E-13
Lateral incident occurs	1.008725E-42	Lateral incident occurs	8.048214E-45
Incident occurs (single runway pair)	2.436000E-13	Incident occurs (single runway pair)	2.448000E-13

Table IV-2
Probability of Incident

Both TACEC and Baseline (current system) yielded a probability of incidence for the longitudinal, lateral and combined occurrence very similar in magnitude. Further analysis is necessary to validate the probabilities used.

V. Capacity Enhancement Analysis

The analysis was divided into two parts. The first part determined the amount of traffic that could execute simultaneous landings onto closely spaced parallel runways at selected airports. Twenty-four airports were selected as being candidates for closely spaced parallel runway operation. The second part used the potential capacity improvements achieved in part one, and evaluated the NAS-wide impact to these new capacities. The evaluation was conducted using the Airspace Concept Evaluation System (ACES) simulation toolbox currently being developed by NASA's AMES Research Center.

Part 1 – Individual Airport Assessment

The airports were evaluated separately using a demand set that modeled a doubling of air traffic as envisioned 20 years from now. This demand set started as a full day of actual arrival and departures for May 17 2002 and was then modified by doubling the flights arriving and departing by creating a duplicate flight. The departure time for each of the duplicated flights was randomly offset from the original by up to 30 minutes. The purpose of this initial analysis was to study unconstrained 2022-like demand, so we set both sector and airport capacities to a high value (500) in order to remove system constraints.

The ACES output data was analyzed to determine whether the application of TACEC could significantly increase the individual airport's arrival/departure capacity. A full day of operations, using the doubled demand set was simulated for each of the candidate airports. They were evaluated to determine the percentage of flights that could have arrived or departed in closely spaced parallel runway groups.

The analysis described above was conducted on each of the 24 airports and an example of the potential increased arrival and departure capacities are shown in Figure V-1.

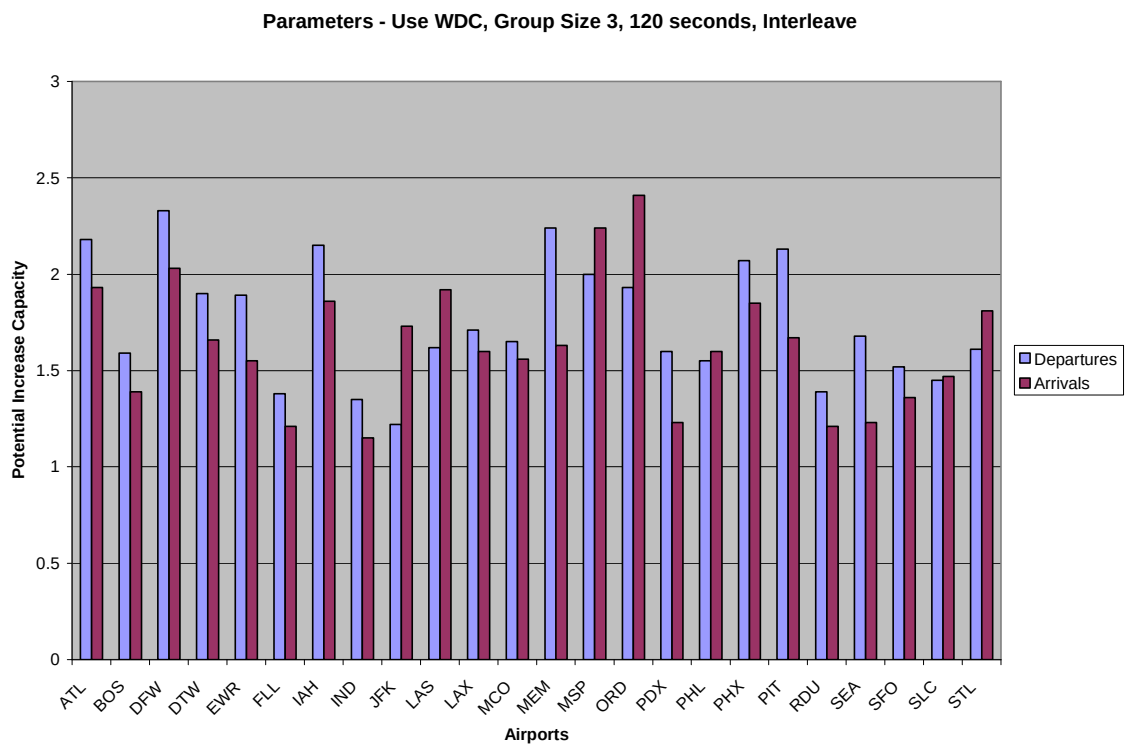


Figure V-1. Arrival and Departure Potential Capacity Increases

Part 2 – NAS-wide Impact

The NAS-wide impact was conducted using a data set, similar to that used in the individual airport assessment, however this time all flights in the data set were duplicated. The file has 60,474 flights, 14,646 flights were rejected during ACES configuration, bringing the total flights evaluated to 45,828.

Sector Capacity \ Airport Capacity	Baseline	TACEC
Baseline	SCENARIO A 1) Baseline/Baseline	SCENARIO C 1) Baseline Sectors, TACEC=Use WDC, Group Size 3
200	SCENARIO B 1) Sectors=200, Baseline Airport	SCENARIO D 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

Figure V-2. NAS-Wide Impact Evaluation Matrix

The first NAS-wide case to be run with the data set was the "ideal" system (all sector and airport capacities set to 200 to eliminate any delays). As shown in Figure V-2, four major scenarios were compared to the ideal case.

Each of the above scenarios was executed in ACES and the resultant delay was tabulated. In the NAS-wide evaluation, delay is calculated as the difference in block times between the scenario under evaluation relative to the ideal scenario.

The derivation of the metrics used in this evaluation is shown in Table V-1.

Metric	Derivation
Block Time	Actual Gate In - Scheduled Gate Out
Delta Block Time	Ideal Block Time - Evaluation Case Block Time
Total Delta Block Time	Sum(Block Time Delta)
Potential Capacity Increase	# of Flights Arriving(Departing)/# of Arriving(Departing)
Delay	Delta Block Time

Metrics
Table V-1

As shown in Table V-2, the Worst Case scenario increases Block Time by 55%. Improving airports to TACEC capacities, but leaving sectors at baseline capacities, provides some improvement, but still produces 40% increase in Block Time. It requires the combination of both sector improvements and TACEC airports to produce less than a 10% increase over the ideal scenario.

	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

Table V-2 NAS-Wide Scenario Total Block Times

The percent Block Time increase in Table 4-1 is calculated as follows:

% Block Time Increase = (Eval. Scenario Total Block Time – Ideal Total Block Time)

VI. Conclusions

TACEC feasibility is addressed by analyzing key performance requirements. The need to meet stringent 4D aircraft positioning accuracy is essential to allow closely spaced parallel approaches while simultaneously avoiding wake vortex hazards. Meeting this performance is possible with the use of modern satellite based navigation systems such as WAAS and DGPS landing aids (LAAS.) However today's aircraft operations and associated avionics are designed for existing ILS/NAVAIDS capability and cannot achieve the accuracy necessary.

It is clear that significant investment is needed to upgrade the airlines' ability to take advantage of TACEC operations. The principal motivator for such investment must be the returns available to the NAS users, these returns must be demonstrated by early implementations that are safe and show real performance gains. Applying TACEC's all weather wake avoidance and parallel approaches at existing airports with runways spaced 3000-4000 ft in 10 years can begin the process of acceptance and cost benefit validation.

The use of ACES to demonstrate the NAS-wide benefits of TACEC has yielded significant results. TACEC, in conjunction with enroute capacity improvements, can accommodate a doubling of today's air traffic – with less delay than we see in today's operations.

A significant finding is the fact that even with a doubling of traffic, the impact at specific airports is not universal. In fact the nature of demand will ultimately drive the optimal capacity increasing solution. Significant more work is needed to evaluate the benefits of TACEC for many different demand scenarios. The use of the May 17th day in the NAS, even when doubling the number of flights to simulate 2022 traffic resulted in only minor traffic increases at a number of our major airports. It would not be possible to justify the expense of a TACEC infrastructure at those airports using these results.

Raytheon envisions TACEC as an evolutionary approach to modernization. Capability improvements can be made based on the projected traffic growth. However the ability to foresee the real growth over time is essential to justify the investments.

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