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RAYTHEON'S ADVANCED CONCEPT DEVELOPMENT ACTIVITIES IN AIR TRAFFIC MANAGEMENT

Kenneth D. Arkind
Raytheon Company
Marlborough, MA

Abstract

Raytheon is participating in the NASA Virtual Airspace Modeling and Simulation (VAMS) program to develop new concepts in Air Traffic Management (ATM) as well as building the simulation capability needed to verify these future ATM concepts. Today's National Airspace System (NAS) is operating at or near capacity, and with projected demand for air travel expected to double over the next ten years, NASA and the FAA are developing new approaches to managing air traffic. Raytheon is utilizing its long history of ATC involvement to look into the future and develop capacity increasing approaches to managing the air traffic, specifically in the terminal domain. At the same time NASA is taking advantage of Raytheon's simulation experience to develop an HLA based NAS wide simulation to evaluate the many new concepts being proposed for air traffic management.

Introduction

This paper addresses Raytheon 's advanced concept development activities in Air Traffic Management. The focus of our efforts is the ATM system we envision in operation in 2022. In the following paragraphs we define the operational environment 20 years from now based on the growth rates defined under NASA's VAMS program. Raytheon is focusing on the Terminal area domain, the key bottleneck in a capacity constrained ATM system. We discuss below our overall concept of a Terminal ATM solution for the future, or Terminal Area Capacity Enhancing Concept (TACEC). We describe the elements required to meet the capacity needs, and the operational approach, including the role of the human operator. Finally we address an example of a core idea or key enabling technology that is essential to achieving the required capacity. We introduce a novel approach to eliminating the constraints imposed by wake vortex avoidance, using Flight Corridors and closely spaced parallel runways to double the capacity of today's airports.

The Problem

Today the United States' National Airspace System (NAS) is capacity constrained by a host of operational and technical issues. A start to mitigating these constraints is delineated in the FAA's Operational Evolution Plan[1] (OEP). OEP address a 10-year horizon and identifies modernization activities that will yield a 30% increase in capacity by 2010 or about a 2% yearly growth. The stated goal of NASA's VAMS activity is a much more challenging 4.2% growth per year over the next 20 years, which more than doubles the number of aircraft operations by 2020 over today's operations. The principal problem therefor is developing operational solutions that dramatically increase capacity beyond the FAA's current goals.

A principal limitation in aviation system capacity arises from the inability to deliver aircraft and passengers into and out of our major hub airports. While there certainly are en route congestion problems that create delays and inefficiencies, the fundamental limitations in aviation system capacity still rest in the terminal areas. If we were able to create tremendous new en route capacity, perhaps through airspace redesign, or automating controller and pilot functions, the limitation of our major airports to accommodate this increased traffic flow is fundamentally limited.

The constraints in the Terminal Area domain are the focus of Raytheon's effort to increase NAS capacity. Providing vastly increased ability to deliver passengers and cargo to their destinations, on time and with acceptable itineraries will require revolutionary approaches to the operation of the terminal airspace and airport surface.

The roots of the terminal area capacity problem are many, and the "solution" to the terminal problem will involve simultaneous improvements in many areas. For the terminal area can be thought of as a series of bottlenecks or potential choke points, any one of which could severely limit the airport, and hence, airspace capacity.

As shown in Figure 1, the terminal airspace must accommodate arrival and departure flight profiles and ground movements. Departure flight profiles

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attempt to move an aircraft most efficiently from departure gate to the point in space which best launches the flight to its final destination. Similarly for inbound flights the terminal airspace must accommodate the aircraft's entry from various points of the compass and provide the most efficient route to its arrival gate.

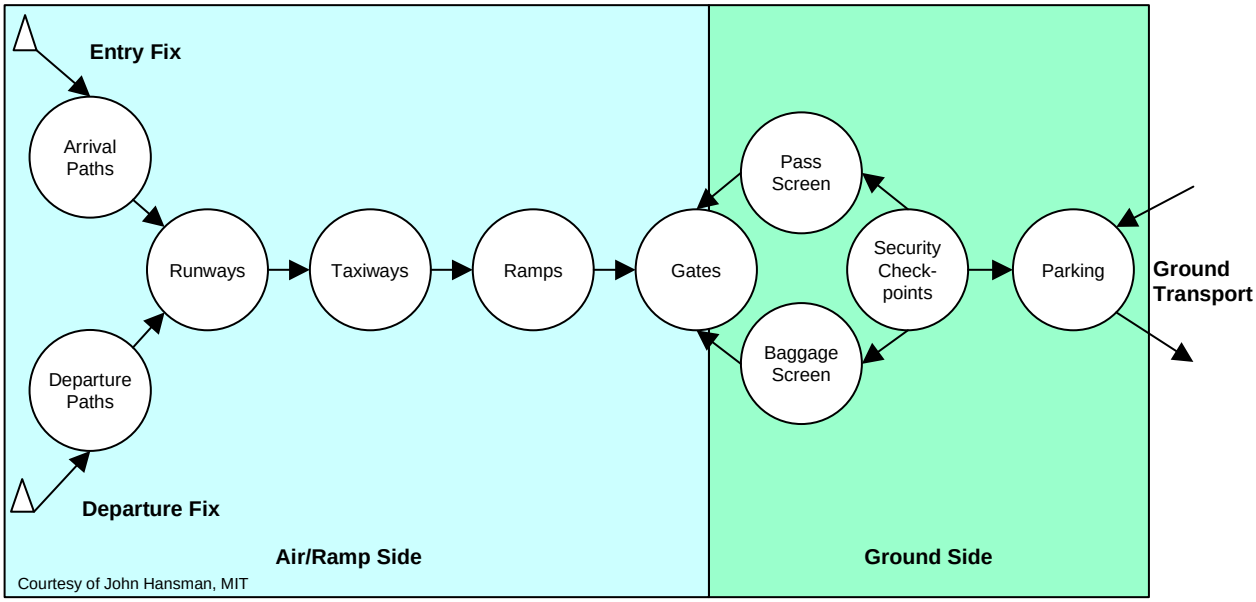

Figure 1. Terminal/Airport System Flows

The fundamental constraints imposed by this process include:

1. The number of aircraft that can safely operate in the volume of space managed by the terminal area (both in the air and on the ground). This is driven primarily by the need to maintain safe distances between the aircraft.
2. The conditions of operation i.e. weather (in particular wind and visibility) and wake vortex induced turbulence.
3. Environmental impacts within the terminal area region.
4. The flight characteristics of the aircraft within the terminal area.
5. Human performance constraints in operating and managing the system.

In addition to the airside operations in Figure 1, there are also a number of constraints on the landside, which in today's heightened security environment may be fundamentally constraining to the goal of increased capacity. Raytheon is only addressing the airside issues under the current plan, however the landside issues will be periodically reviewed. Delivering greatly increased arrivals requires both gate and people moving capability to match. Groundside operations for the airlines and airport facilities are not infinitely expandable, and hence new strategies are needed to truly deliver the air transport capability the public demands.

The Requirements

Since the focus of TACEC is the terminal area, which encompasses both the Terminal domain and the Surface domain, we can compare VAMS capacity requirements directly with the FAA's Operational Evolution Plan (OEP), specifically the "Arrival and Departure Rate" analysis for current and future capacity. Different regions of the NAS reflect different capacity needs, to provide a system wide view the OEP utilized 30 benchmark airports as a means to focus benefits analysis and to improve delays experienced today in the "Arrival and Departure" environment.

The FAA expects these benchmark airports to see a growth of 11,000 more operations per day (24% growth) by 2010. Using the VAMS 4.2% growth model, this translates into 54,000 more operations by 2020. See Figure 2

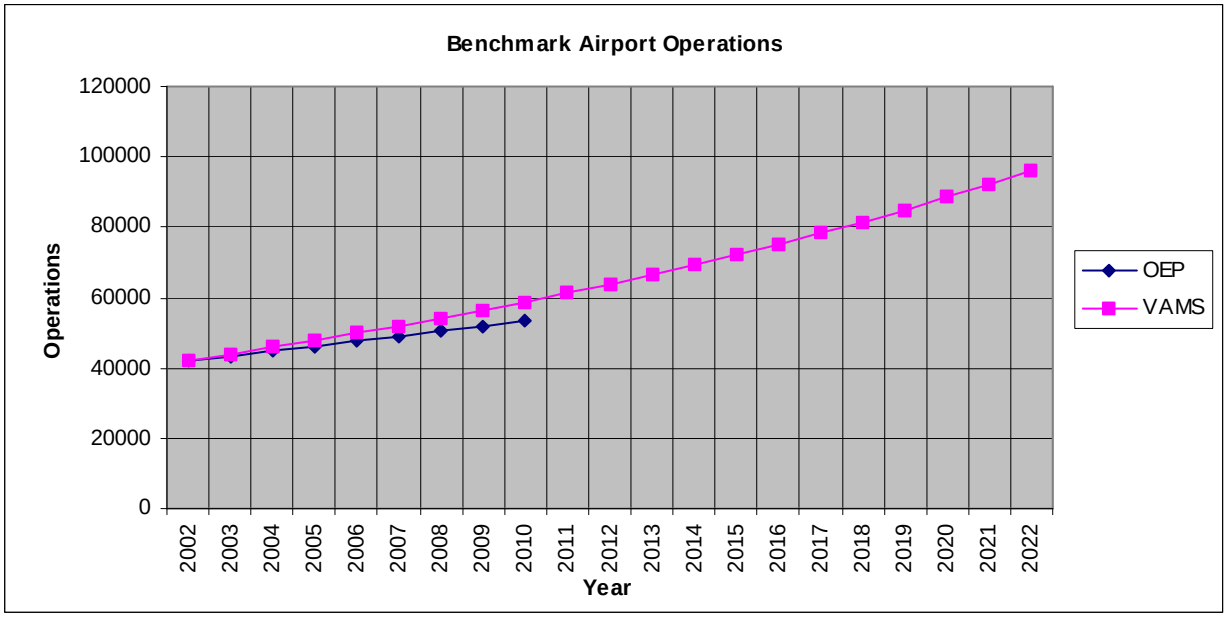

Figure 2. Capacity Requirements

Not surprisingly the OEP postulates that of the 11,000 additional operations needed in 2010, 6800 will come from building new runways at key airports.

It may not be realistic to assume that an additional round of runway building over the following 10 years will happen. Hence the specific challenge for the VAMS Terminal Area capacity-increasing concept is to maximize increased operations by using new technology and operational/procedural concepts, far beyond those envisioned by the FAA's OEP. Any remaining shortfall in available capacity would then dictate the need for further construction of new airport facilities.

Raytheon has assumed the distribution of daily operations remains similar to today's airport usage, 40% of the 30-benchmark airports will see the majority of the additional flights. This distribution arises due to the "hub & spoke" strategy used by the major carriers today. If an alternative strategy was adopted this would alter the specific airports used, but would likely still require dramatic increases in arrival/departures at these different facilities.

Extrapolating the 20-year growth over the busiest airports would set a requirement for operations per hour shown in Table 1.

Table 1. Required Operations in 2020

OPS per HR			
AIRPORT	TODAY	OEP/2010	VAMS/2020
ATL	185	237	426
ORD	200	236	460
DFW	261	316	600
LAX	148	185	340
DTW	143	187	329
PHX	101	132	232
MSP	115	152	265
LAS	84	109	193
MIA	124	153	285
DEN	204	251	469
CVG	123	172	283
BOS	118	125	271
STL	104	135	239

To meet the demand in airport operations per hour in 2020 requires arrival and departure rates to double beyond those now planned for the OEP 2010 solutions. This increase will come from operating twice the number of aircraft within the same airspace and on the airport surface. This focuses the challenge for TACEC operation in the following key areas:

Separation between aircraft within the terminal airspace must be reduced by up to a factor of 2.

1. Final approach and departures must be conducted at up to twice the rate achieved by the OEP improvements.
2. Surface traffic must be increased by up to a factor of two.
3. Gate operations must double either by increasing their number or halving their occupancy.

TACEC – Terminal Area Capacity Enhancement Concept

As illustrated in Figure 1 the constraints on terminal operations include arrival/departure paths, runway, taxiways and gates on the airside operation. Each of these flow elements has been decomposed and its contribution to the congestion problem articulated. A collection of ideas, or conceptual frameworks, is identified as possible approaches to alleviating the impact of each constrained resource.

Whatever concept elements or ideas might be conceived of, the overall TACEC concept involves (1) implementing many concept elements that address capacity bottlenecks, and (2) providing a high level of automation and synchronization to the currently asynchronous air traffic management system. This will permit optimal use of all available resources, maximizing the performance that the system can deliver, and ensuring a highly safe environment in a highly stressed system, operating near its capacity limits.

A systems analysis, based in large measure on existing air traffic management literature, was conducted to identify the contribution of each element of the terminal system to overall system capacity limitations. This included examination of various runway configurations, high speed taxiways, wake vortex limits, limitations imposed by terminal area separation standards, controller workload, limited taxiway, ramp, and gate capabilities. Aircraft equipage and performance is a key element of capacity as well and will be reviewed in the future as part of Raytheon's efforts. A limited investigation into terminal limitations imposed by enhanced security screening measures and limitations on groundside access to the airport will also be done.

From the analysis the following concept elements are considered part of the TACEC.

1. Improved surface traffic management.
2. Integration of departure, arrival, and surface management systems
3. Integration of Airline ramp and gate management within the overall Terminal operation.
4. Reducing Runway Occupancy Times or alleviating their impacts.
5. Reducing Wake Vortex separation constraints.
6. Further decreasing longitudinal separation standards by introducing self separation and self merging of arrival streams
7. Precise 4D delivery of aircraft to the runway threshold
8. Multiple dynamic 4D RNAV approach and departure corridors
9. Alleviation of noise and pollution impacts of airport operations via flight path control and more efficient airport surface operations
10. Potential capacity gains through more autonomous aircraft operations in the terminal area
11. Revolutionize the current paradigm of air traffic Control to air traffic Management. Provide the Human Centered capability to safely and efficiently manage air traffic in the Terminal area.
12. Techniques to permit closely spaced parallel runways in all weather conditions.

Resting on top of any and all of these concept elements is a highly automated optimization scheduler that maximizes airport throughput subject to whatever residual constraints remain after all concept elements is fully implemented. This will in all likelihood also require infrastructure improvements such as high-speed data link, ADS B, highly automated 4D guidance systems, and highly automated 4D scheduling systems.

TACEC Operational Discussion

TACEC is a highly automated solution to the movement of aircraft throughout the terminal area (both airspace and ground space). Raytheon's vision of terminal area operations in 2020 also requires a NAS –wide framework to support such automation.

The arriving and departing aircraft within the airspace managed by TACEC will be operating in a highly integrated NAS–wide environment. Flight planning will be 4D based, and operations throughout the NAS will be driven by time based operations. The terminal will receive/send aircraft from/into the surrounding airspace in accordance with specific lat/long/altitudes. This transition point must be reached at a specific time as dictated by

the respective 4D profile negotiated with airline and air traffic requirements long before the aircraft's planned departure.

This transition point (entry or exit into terminal airspace) will be used as one of the boundaries for Raytheon's study of the terminal area. The other boundary will be the arrival/departure gate. This view redefines the terminal airspace from the partitioned, multi-sector complexity of today to a solid cylinder, whose radius is based on maintaining the necessary precision surveillance and height on operational altitudes.

TACEC will use a high fidelity analytical capability, embodied in a data processing facility that reflects the technology expected in 2020. This terra-flop-processing horsepower will be used in conjunction with years of development in characterizing aircraft performance, weather prediction, sensitivity analysis, and autonomous computer operation to derive continuously updated flight profiles. These flight profiles will be optimized to direct all aircraft in the terminal area between the boundaries defined above. Optimization criteria will include minimal cost of operations, minimal delay, as well as other issues to be evaluated.

It is important to note that these flight profiles accommodate all aspects of the aircraft's movement, including but not limited to:

1. Conflict detection and resolution
2. Separation from all hazards, including terrain, weather, wake vortex turbulence, SUA, etc.
3. Surface movement from/to runway threshold to gate to runway.
4. Noise avoidance and emissions control
5. Emergency operations

In today's terminal operations this activity is handled by a combination of procedures and Air Traffic Controller decision making. Separation assurance is the responsibility of the air traffic controller. Because the number of terminal operations is expected to double by 2020, the ability of humans to perform this process in a safe and efficient manner is questionable. A re-distribution of these tasks between computer and human is envisioned. Separation assurance can no longer be the solely delegated to the ground controller. The over-arching principle behind this redistribution is maintaining a Human Centered Operation.

Human Centered Operations is a key element of the Terminal Area Capacity Enhancement Concept. Although there is a great deal of automated operations and computational activities envisioned, the focus of the system remains human centered. This is achieved by delegating functions best performed by the computer to automation, while enhancing the ability of the human to perform those tasks that are best done by humans. See Figure 3

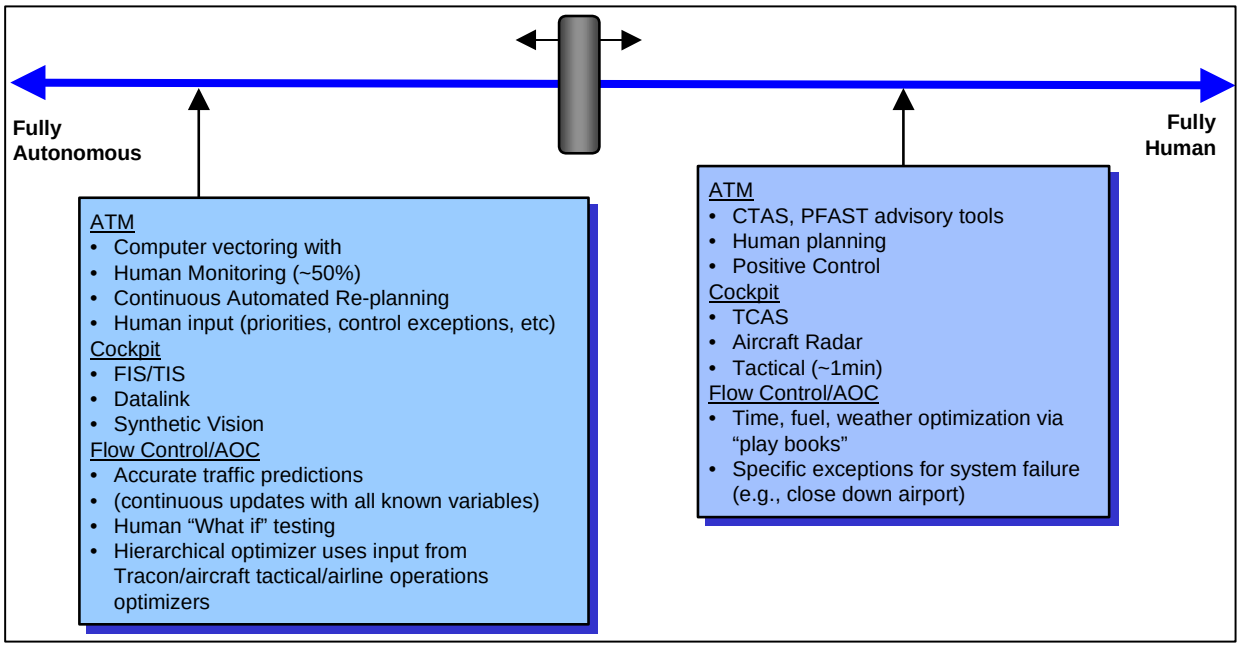

Figure 3. Human vs Machine Tasking

Calculating optimal flight paths can be done best by a computer…. given the required information is available. The complexity of this calculation (and its accuracy) will require significant processing power and knowledge of the NAS and its component operational characteristics. A basic tenet of the TACEC study is that processing can be accommodated by future digital processing hardware, and the characteristics of the aircraft and the operating environment are well known.

Monitoring the results is not easily done by the computer…the criteria for judgement in a dynamic environment is very hard to model and a computer-based solution is easily foiled. But human assessments have proven reliable in assembling complex inter-relationships and judging the outcome if they have the right information.

Monitoring can best be achieved by providing appropriate situational awareness and insuring human involvement in the events that make up the "situation". This usually means human decision making activities must be conducted in the establishment of the "situation" such that the build up of the current state has commitment from the human monitor.

This requires a process similar to the current "hands on" controller activities used to direct approach and departure. But instead of the controller directing the aircraft through terminal airspace, he must achieve the same involvement whilst monitoring the aircraft's compliance with the optimized flight path. Ostensibly the task of monitoring is less intensive and allows the controller to handle more flights, with the appropriate level of commitment to the airspace situation to ensure safety. Similarly the flight crew must develop the same situational awareness to perform a similar safety critical role.

This process will combine new visualization approaches to achieve enhanced situational awareness with a built in continuous learning process. By performing the necessary monitoring effort the controller will simultaneously be "trained" in the ongoing air traffic situation. This training is accomplished by visual stimulus and programmed tasking to ensure adequate responsiveness to abnormal situations.

The heartbeat of the TACEC system is the optimized 4D flight profiles, but implementation requires dramatic differences in all terminal operations. Because all aircraft must operate to exacting location and time constraints it is envisioned that FMS/auto-pilot controlled flights will be required within the terminal airspace and on the airport surface at all times.

The optimal flight profile must be data linked to the aircraft prior to entering terminal airspace, and following confirmation by the flight crew (using advanced CDTI tools) and ground manager the control of the aircraft will be transferred to the FMS driven auto pilot. Both air and ground operations as well as the onboard FMS will monitor conformance to the required flight profile. By onboard monitoring of the actual flight profile the aircraft's future location (intent) is data linked to the terminal ground facilities. This intent information is then used by the trajectory optimization calculation to update the required flight profile, which is then sent back to the aircraft. This closed-loop control process provides the necessary action/reaction to maximize safety and efficiency of aircraft operations within the terminal airspace.

Clearly this transfer of crucial flight information requires extremely reliable data links. Air Ground Air communications to hundreds of aircraft will utilize highly bandwidth efficient RF links, incorporating the advances in digital communications envisioned over the next 20 years.

TACEC also envisions surface movement (both aircraft and other vehicles) to be automatically operated similarly to the airspace movement. Specifically the optimized taxi route between gates and from/to the runways will be derived from continuously updated "situational reports". In the physically constrained airport surface area a high capacity "wireless LAN" would be used to transfer information. Aircraft, ground vehicles, and support facilities would have complete information on all movement and locations. High data rates will allow the needed fidelity to transmit taxi routes and monitor compliance. Once again the aircraft's movements will be controlled by an onboard auto-taxi system driven by the optimized routing transmitted over the LAN.

TACEC CONCEPT – Technology Application Discussion

The TACEC concept utilizes a number of future ATM technology enhancements or Core Ideas, to enhance terminal operational capacity. The following discussion outlines how TACEC decomposes the known bottlenecks in the terminal environment and applies these core ideas to increase capacity. Alleviating these bottlenecks through technology innovation is only part of the contribution TACEC makes to meeting NASA's

goals of doubling the nations air traffic capacity, infrastructure changes are also required to realize the goals.

Figure 4 illustrates the decomposition of the known bottlenecks associated with the Terminal/Airport System discussed earlier (See Figure 1), albeit only the “Air” System. In the future the “Land Side” may become the primary constraint to overall capacity. These land side operations will be studied in future activities, for now the focus will remain on the air side elements. The application of TACEC technology will ultimately address each of these elements within an overall system solution that can provide maximum terminal area capacity for the available technology in the year 2020.

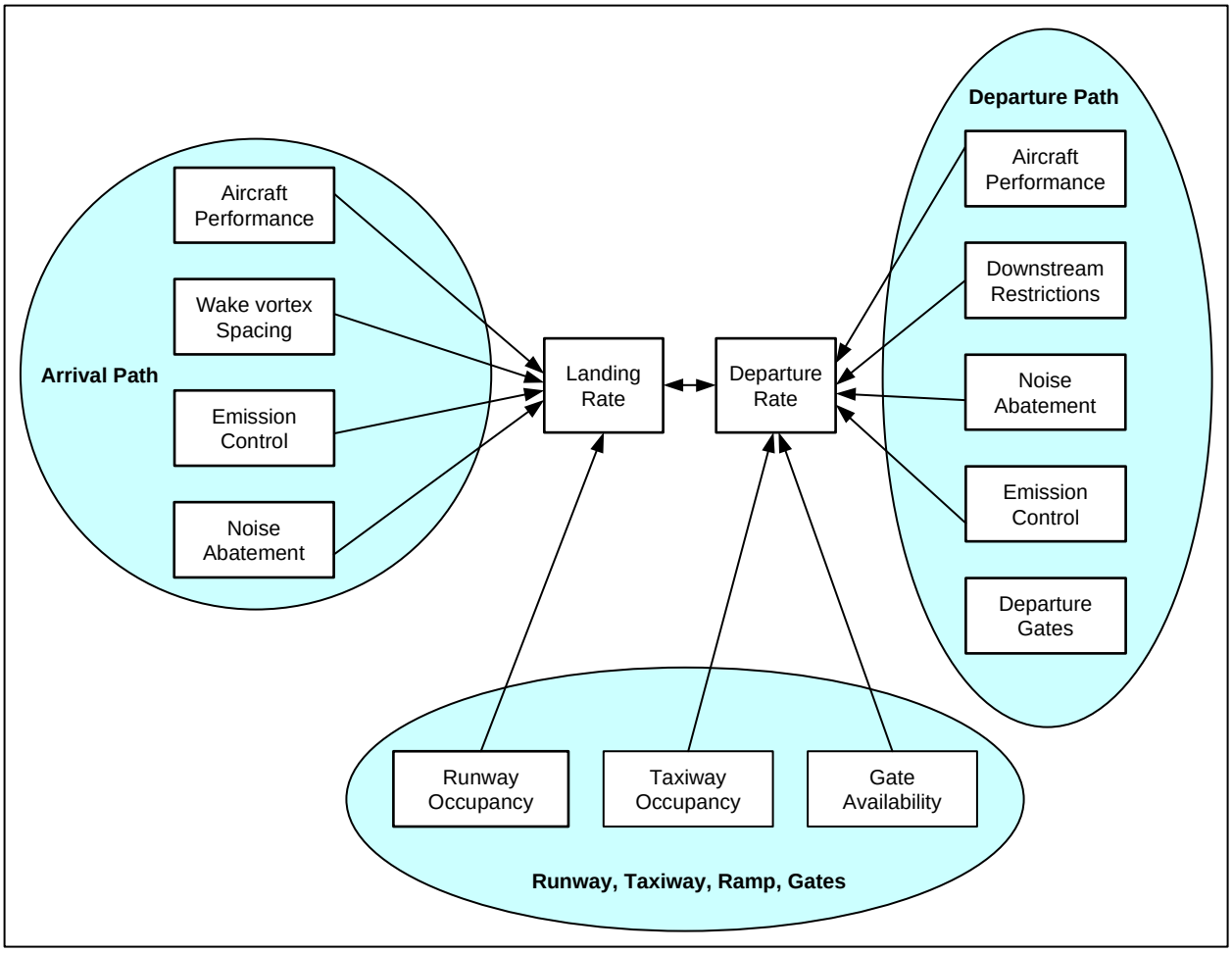

Figure 4. Terminal System Flows Decomposition

Note also that the trade-off between arrivals and departures must be part of any capacity increasing study. Maximizing runway usage by allowing mixed operations can significantly improve an airport’s capacity. TACEC can provide the necessary scheduling accuracy to allow arrivals and departures to use the same runway.

An example of a technology solution applied to the wake vortex separation element is contained in the next section.

Wake Vortex Avoidance

Wake vortex reduces the capacity of the NAS by restricting flights through airspace that contains disturbance generated by another aircraft. The FAA’s operational procedures, FAR 7110.65M has a myriad of constraints imposed on aircraft separation based on type, weather, sequence, etc. Table 2 summarizes the primary examples, basically aircraft separation is used to insure the trailing aircraft is not impacted by the leading aircraft’s wake vortex.

Table 2. Example of Wake Vortex Constraints

Arrival (IMC and low-VMC only)	Departure (All times)
Behind heavy, B757, or other large aircraft	Between heavy, B757, or other large aircraft
Separation Requirements = 4-6 miles	Separation Requirements = 4-5 miles or 2 minutes
Parallel Runways (IMC and low VMC only)	**Intersecting Runways (All times)**
Behind heavy, B757, or other large aircraft treated as a single runway when runways separated by <2,500 ft	When airborne B757 or heavy jet passes intersection
Separation Requirement = 4-6 miles	Separation Requirement = 4-5 miles or 2 minute wait

Significant work has gone on to investigate the characteristics of Wake Vortices to allow detection and prediction of their presence. In general the 7110.65M requires a conservative approach to managing air traffic to insure minimal impact to aircraft operating in their vicinity. NASA's AVOSS[2] activity has attempted to measure, analyze and assess Wake Vortex characteristics and offer alternatives to the present ATC operations for Wake Vortex management.

Essentially mitigation of wake vortex requires spacing between aircraft that exceeds or avoids the region of vortices. The knowledge of just how large an area and how this disturbance moves has been studied and recommendations made to adjust the current separation standards accordingly. An example of an operational approach to reducing wake vortex impacts is currently the High Approach and Landing System (HALS) developed by Germany's DFS and used in Frankfurt Airport since 2001. A 1700-ft separation between parallel runways requires wake vortex separation to be imposed in IMC conditions. HALS advises a displaced runway threshold on one runway that maintains the required separation on the other runway between a heavy/B757 and smaller aircraft.

Concepts to reduce the impact of wake vortices typically include one or more of the following techniques:

- Wind advisories
- Time based separation for arrivals
- Actual Wake hazard advisories
- Displaced thresholds
- Arrivals offset by angular separation to achieve lateral separation
- Revised separation standards (based on aircraft type & weather)
- Dynamic wake vortex separation standards
- Simultaneous Offset Instrumentation Approach (SOIA)
- Paired/formation approaches and departures

The focus of the TACEC approach to wake vortex mitigation lies in minimizing the impact on landing and take-off rates. In so doing this will allow a greater arrival and departure rate and increase the system capacity.

Wake Vortex Mitigation – Core Idea

Raytheon's core idea for wake vortex avoidance utilizes the idea of "flight corridors" as described by Rossow[3] wherein wake vortex avoidance is accomplished by maintaining flight paths within the corridors. Flight corridors are time dependent spatial regions defined by the characteristics of the wake vortex spreading. Wake vortices generate hazardous forces on other aircraft, primarily a rolling-moment coefficient, when they fly in the wake-hazardous region. This region is characterized by a time dependent spreading function and by the atmospheric conditions. Flight corridors can be established as a function of the aircraft's performance, and the knowledge of where the vortices are versus time. See Figure 5. This contrasts the current paradigm of maintaining sufficient in trail spacing to insure the dissipation of the wake vortices.

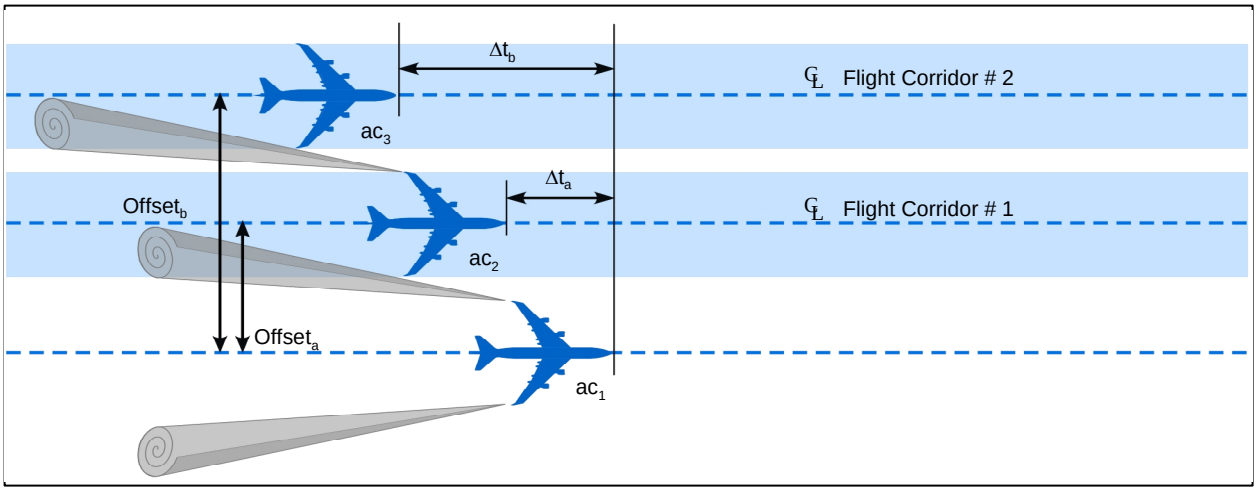

Figure 5. Flight Corridors to Avoid Wake Vortices

The obvious benefit of such a wake vortex avoidance approach is the ability to significantly increase the number of aircraft both arriving and departing the terminal area. Instead of large time separations between aircraft necessary to wait for wake vortex dissipation, aircraft must maintain very short time separations to stay ahead of the wake vortex spreading.

The challenge of such operations is the necessity to operate aircraft with significantly more precision than currently required. Knowing exactly where the aircraft is in space and time is essential. Controlling where the aircraft is to fly must accommodate not only for the wake vortex avoidance issue but also the aircraft's performance, potential conflict with other aircraft or local hazards, and current terminal area conditions. The maintenance of precise flight paths requires FMS/auto pilot operation using uplinked trajectories for all terminal airspace operation. Raytheon is investigating the implementation of this approach based on the current capabilities of he FAA's Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS) to provide precision navigation information. Also advances in AGA data links, flight management systems, and flight control integration must be developed to insure the accuracy and integrity needed for safe operation.

Finally the application of flight corridors to wake vortex avoidance must be accomplished as part of an overall human centered solution for the terminal area operation. The role of the human, albeit in the cockpit or on the ground, must be redefined.

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