AIAA Guidance, Navigation, and Control Conference and Exhibit
11-14 August 2003, Austin, Texas

AIAA 2003-5768

A Point-To-Point Concept for Improved National Airspace System Capacity

David Schleicher[†], John Sorensen[o], Brian Kiger*, Alex Huang[^]

Seagull Technology, Inc., Campbell, CA 95008

Abstract

In order to significantly improve future National Airspace System (NAS) capacity, a new air transportation operational concept is being developed. The concept – based on using massive point-to-point (PTP) flights and on-demand air transportation – is to enhance the NAS payload capacity by both relieving the throughput-limited hub-and-spoke airports and by providing more direct services to the traveler or shipper. The central premise that drives development of this concept is that there is a growing demand for more time-efficient, hassle-free, point-to-point and on-demand air transportation that better serves the traveling public and cargo shippers from door-to-door than can be provided through increased connections through the larger airports alone. The PTP concept more fully utilizes the non-hub-and-spoke public airports across our country and connecting airspace to meet this demand.

In this paper, we describe a number of the core features of this new concept and examine the potential flight operational improvements that can be facilitated by the concept for Year 2020 operations in the Los Angeles basin.

Introduction

Since the passage of the Airline Deregulation Act in 1978, the steady average growth in air transportation operations has very often pushed the aviation system in the United States to the brink of gridlock, most notably at the top 31 busiest air carrier airports and in the airspace directly surrounding them. Flight delays and missed connections have often reached intolerable levels for millions of airline customers.

All performance indicators show the pre-September 11, 2001 trend of customer service to be increasingly inferior to that in previous years. The average on-time percentage had dropped from 78.3% during the period of September 1987 to 72.6% in December 2000[1]. Passenger complaints filed with the United States (US) Department of Transportation (DOT) in 2000 totaled 23,381, which is 14% more than that in 1999. Of those filed with the DOT, 40% are for flight-related problems, such as flight cancellations, flight delays and misconnections. A major reason for flight delays is that the current aviation system infrastructure is unable to cope with the growth of flight traffic because its capacity is inadequate, especially at hub airports.

Although commercial flight operations dropped after the terrorist attack on September 11, 2001, it is believed that air traffic will return to the pre-September 11 levels by 2004. Commercial traffic overall is expected to increase at an average annual rate of 4.1 percent after 2004 for at least the following 9 years[2]. Hence, delay is again looming as a critical limiting factor to hub-and-spoke-based capacity growth in the foreseeable future.

Airport delay may not reveal the true nature of hub gridlock. Airline scheduling schemes, inclement weather conditions, and individual air traffic service provider (ATSP) workload and productivity limits are also factors that contribute to the delay.

According to the Federal Aviation Administration (FAA) Operational Evolution Plan (OEP)[3], 90% of the delay is experienced at 31 benchmarked hub airports, and demand will grow by 200 million passengers at these airports over the coming decade. Building more runways at these locations to absorb the projected growth in air transportation is politically and economically very difficult and a strategy with diminishing returns given increasing airspace complexity. Squeezing aircraft operations closer together will help but this does not represent a long term solution.

[†] Project Co-Manager, Air Transportation Group;
E-mail: dschleicher@seagull.com. Senior Member, AIAA.

[o] Project Co-Manager
E-mail: jsorensen@seagull.com. Associate Fellow, AIAA.

[*] Senior Systems Engineer, Air Transportation Group;
E-mail: bkiger@seagull.com. Member, AIAA.

[^] System Engineer, Air Transportation Group;
E-mail: ahuang@seagull.com.

Copyright © 2003 by the American Institute of Aeronautics and Astronautics, Inc.
The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Governmental purposes.
All other rights are reserved by the copyright owner.

A New NAS Operating Concept

The central premise of the Point-to-Point (PTP) concept is that the National Airspace System capacity can be increased significantly by facilitating and incorporating massive use of point-to-point and on-demand commercial air transportation from a greater number of public airports than are used in today's hub-and-spoke configurations. This central premise is based upon the facts that there are both (a) an availability of over 5000 under-utilized public airports to choose from; and (b) a growing demand to use these airports for more time-efficient, hassle-free, point-to-point, on-demand air transportation that better serves the traveling public and cargo shippers[4].

To enable the PTP concept, current ATM and flight operations infrastructure systems, aircraft fleets, and commercial aircraft operations management processes (e.g., air and cargo carriers, fractional jet ownership organizations, business aircraft operators) would all need to be augmented and enhanced. The current hub-and-spoke paradigm used by the large air carriers will be less and less capable of providing timely, efficient services as the hub airports reach their throughput limits. Also, the hub-and-spoke system has limits to growth without undergoing the very expensive, politically unattractive process of building more runways at the hub airports.

The PTP concept postulates that NAS flight capacity (defined as the number of passengers and volume of freight served within a normal business day) can be increased by:

1. Complementing the hub-and-spoke (HS) flight schedule from the viewpoint of the customer, with more alternate PTP flights that bypass hub airport congestion;
2. Utilizing more of the smaller public or underutilized military/government operated airports to serve as flight origin or destination points for PTP flights with the additional advantage that these airports could be closer to the intended starting and/or ending points of the trip;
3. Utilizing a greater spectrum of aircraft sizes and types to more economically meet the individual payload capacity (i.e., number of passengers or volume of cargo per flight) demands for the increased number of distributed origin-destination (O-D) airport pairs; and
4. Providing increased <u>on-demand</u> PTP air taxi-like service to complement the <u>scheduled</u> HS and PTP service.

In other words, a larger spectrum of aircraft types using PTP flights to and from the currently underutilized airports can (a) unload the hub airports; (b) provide large numbers of users with more direct, shorter travel time to the desired destination; (c) provide more efficient transportation services to the nation's growing distributed smaller communities and expanded urban areas; and (d) offer on demand service as required to meet specific customer needs. This concept is depicted in Figure 1.

Figure 1 The Point-to-Point Concept

PTP Concept Core Ideas

The PTP concept is characterized in a set of six integrated core ideas:

1. <u>Airport Air Traffic Management (ATM)</u>. Provide towered and non-towered airports with the ability to handle enhanced low visibility operations via airport ATM automation, airport lighting system automation, precision landing guidance systems, and related infrastructure;
2. <u>Terminal Area ATM</u>. Utilize time-based and integrated ATM-flight management automation to provide even, regulated traffic flows along flexible paths within dense regional terminal areas servicing both large and small public airports in these regions;
3. <u>En Route Airspace ATM</u>. Integrate strategic ATM (traffic density management and flow control) and flight management automation processes within dense en route airspace, and utilize a new airspace design, free flight mechanisms, and communications, navigation, surveillance (CNS) technologies that move away from today's static sector mode of operation;
4. <u>Traffic Flow Management (TFM)</u>. Expand the TFM functions to encompass the flow control needs of all providers of air transportation, to assist in optimizing each flight from the providers' business perspectives;

5. Fleet Operations. Integrate all commercial fleet (including air carriers, air taxis, business jet, uninhabited aerial vehicles (UAV) and rotorcraft operations) ground operations and dispatch functions with the ATM/TFM functions encompassed by the first four core ideas; and
6. Flight Deck Management and Avionics. Accommodate a broader aircraft type spectrum with advanced avionics designed to work directly with ATM and Fleet Operator automation tools and advanced ATM and flight operations procedures.

The core ideas are integrated via an over-arching planning, management and control function that coordinates the entire air transportation system. This coordination function resides within the TFM organizational realm. Some level of synchronization of the traffic flows is necessary, to achieve maximum performance and to minimize adverse interactions between PTP aircraft and aircraft operating out of our high density hub airports. Synchronization processes accommodate the on-demand services while simultaneously producing the schedule reliability and safety levels required for commercial operations. Aspects of core ideas 1, 2 and 6 are now described. Each of the core ideas and associated CNS and weather information system requirements has been recently fleshed out in more complete detail.[5]

Core Idea 1: Provide Auxiliary Towered and Non-Towered Airports with Enhanced Low Visibility Operations and ATM Automation

Concept PTP expands commercial air transportation services by making greater use of more of the public airports (and those private or government owned airports that might be made public, such as NASA's Moffett Field). Upgrading auxiliary airports so that they are capable of supporting commercial air transportation is a fundamental requirement if payload capacity is to be increased by a factor of two or more within the next twenty years.

The assumption that we make is that each major (hub-spoke) airport is increased in utilization up to its practical throughput limit (as assigned today), and thereafter the spillover is moved to adjacent underutilized, although smaller airports. For example, in the Northern California Bay Area, the major commercial airports of San Francisco, Oakland and San Jose (SFO, OAK, SJC) would increase in utilization from today's annual operations to some multiple that would represent the limits of their practical throughput. Thereafter, additional commercial services would be offered from surrounding "satellite" airports such as Santa Rosa, Half Moon Bay, Walnut Creek, Livermore, Moffett Field, and Watsonville.

A complementary assumption that we make is that there is a pent up demand for more PTP travel via regional airline jets, business jets, and other aircraft. This will cause increased demand and higher passenger and aircraft traffic levels at the satellite or "reliever" airports. The satellite airport traffic will increase along with the hub traffic until the hubs are saturated. At that point, there will be an even greater increase in traffic levels at the satellite airports.

Of the example satellite airports, some have existing air traffic control tower (ATCT) services and others (e.g., Half Moon Bay, Watsonville) do not. Thus, there is a need to supplement the current controller-provided services at the towered airports with automated ATM services at the non-towered airports. (Here, it is assumed that it is more economically feasible to provide airport ATM automation than it is to build and staff new ATCT at airports where none exist today. It is also assumed that throughput can be increased at towered airports by additional automation.) In each case, the satellite airports would be provided with technology required for safe low-visibility IFR operations and ATM services integrated with the regional terminal ATM system.

Non-Towered Airports

For those airports without control towers, the ATM services are provided by a ground-based automation system eliminating the need for building and operating control towers. Such an automated airport design was first implemented by the FAA[6] in 1976 and has since been updated in new nontowered airport system designs.[7,8]

A high level operational architecture layout of such a system is depicted in Figure 2.

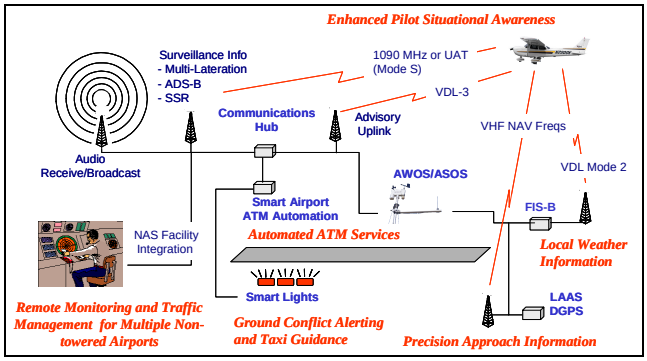

Figure 2 PTP Automated Airports

The PTP automated airport includes the following major components:

1. Multi-mode surveillance system – Surveillance is provided by fusing together, as available, secondary surveillance radar (SSR), automatic dependent surveillance-broadcast (ADS-B), and transponder-

based multi-lateration. ADS-B and multi-lateration provide precision coverage in the absence of SSR coverage.

2. Integrated weather data – Airport weather conditions are obtained from on-site Automated Weather Observing System (AWOS) or Automated Surface Observing System (ASOS) stations that regularly measure and digitize wind speed and direction, barometer setting, etc. Winds aloft are provided via land line and may be locally updated via downlink of aircraft in situ measurements.
3. Local Area Augmentation System (LAAS) – The LAAS ground station is used to augment the Global Navigation Satellite System (GNSS) by providing data to remove most of the error in the GNSS-derived position. LAAS is used to enable approaching and departing aircraft to fly precision paths in low visibility conditions.
4. Lighting automation – Runway lights are automatically turned on during instrument meteorological conditions (IMC) and nighttime flying by sensing use of the runway by the ATM automation system. Other lights are used to lead the aircraft during taxi operations, to signal whether it is safe to cross airport intersections or enter the active runway.
5. ATM automation – This system uses information from the surveillance and integrated weather components to provide the basic ATM services to the aircraft that would normally come from the ATCT. These services include:
    a. Airport conditions advisory (including runway in use and number of aircraft in the pattern) and the conventional ATIS information;
    b. Traffic advisor (pointing out each aircraft's adjacent traffic);
    c. Takeoff and landing sequence advisor (including takeoff hold and provision for touch-and-go or missed approach);
    d. Conflict detection/loss of separation advisor;
    e. Optionally, a sequential spacing advisor to ensure safe separation between consecutive operations and adjacent flight paths (Note: The self spacing function could be mechanized within an autonomous aircraft avionics suite.); and
    f. Emergency services advisor (to provide vectors to lost aircraft and most recent position of aircraft with open flight plans).

Advisory messages would be both data linked and voice broadcast (via synthetic voice mechanization) to each aircraft.

6. Communications hub – This function connects the non-towered airport with the rest of the NAS, and it communicates or provides the following:
    a. airport status and the state of its operations to the regional ATM system in order that the regional system can monitor or regulate flow of aircraft into and out of the airport with respect to the general regional flow;
    b. automatic opening and closing of filed flight plans for aircraft using that airport;
    c. the interface to the data link facility;
    d. aircraft and airport operational status with the various aircraft fleet operators who use the airport; and
    e. the mechanism for remote surveillance of the airport activity by the regional ATM organization to facilitate security measures.
7. Non data link communications – For non-data link equipped aircraft, the ATM and weather information is synthesized into voice and broadcast using the common terminal airspace frequency (CTAF). Voice recognition is used to digitize pilot radio messages such as log-in, intent, and "ROGER/WILCO" type messages.

The minimum equipment an aircraft needs to operate in such an environment is a radar transponder and a VHF radio.

Each runway at the non-towered airports is provided with an established set of anchor points that incoming aircraft are directed to. These waypoints indicate the beginning of the following final approach paths that are non-interfering with surrounding airport traffic. In turn, the approach patterns establish the corridors for departing traffic. The scheme is shown in Figure 3.

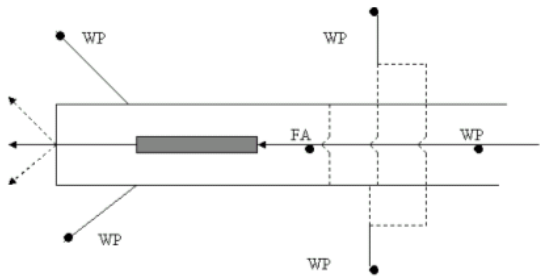

Figure 3 Typical Non-towered Airport Anchor Point Scheme

The following features are included for sequencing and spacing of arrivals and providing for departures:

1. ATM Automation computes the sequence (and optionally, the spacing) advisory and transmits that information to each aircraft operating within the

vicinity of the airport (e.g., 5 nmi.). Examples would be "No. 2 in the sequence, turn to base"; "turn to downwind;"

2. Arriving aircraft enter at the fixed anchor points with appropriate fixed headings, and anchor point timing is used if the aircraft avionics is capable of driving the aircraft to a "required time-of-arrival" (RTA). Right and left patterns are both used when feasible. Straight in approaches have priority over aircraft approaching from downwind;
3. Gaps are placed in the arrival stream to accommodate departures. Departures provide direction intent to time turns to crosswind direction;
4. Go around, touch-and-go (pattern work) intents are known and used to blend aircraft back into the arrival pattern; and
5. If equipped, the aircraft multi-function display (MFD) shows each aircraft its immediate leader in the sequence and the associated spacing constraint (e.g., a slot or spacing bar);

Note that this technology would also serve airports during when the towers close for periods of time.

Towered Airports

For the towered airports, we envision including many of the advanced developments already underway to increase runway and airport capacity as well as taxi efficiency and safety.

Each runway at the higher volume towered airports is also provided with an established set of flight path anchor points. These waypoints indicate the beginning of the following approach patterns that are non-interfering with surrounding airport traffic. In turn, the approach patterns establish the airspace available for the departing traffic corridors. Such an approach waypoint/traffic pattern scheme for aircraft that arrive and depart on different non-crossing runways is illustrated in Figure 4 and 5.

In Figure 4, the following features are included in terms of sequencing and spacing of arrival aircraft:

1. ATM Automation computes the arrival sequence and runway assignment;
2. ATM Automation computes the required arrival spacing (using wake vortex and runway occupancy time constraints);

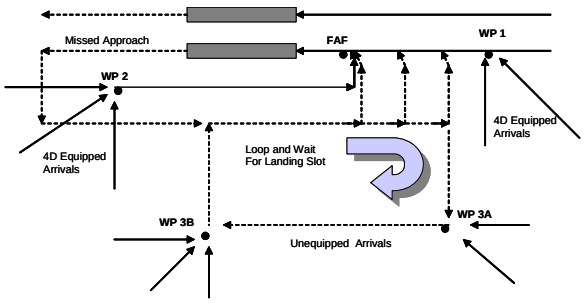

Figure 4 Typical Towered Airport Anchor Point Scheme

3. Inter-aircraft spacing is given in time periods between consecutive aircraft over the runway threshold, starting with the Lead aircraft in a given string. The timing of the arrivals is adjusted by the airport surface decision support tool (DST), or ATM automation system, for subsequent taxi coordination;
4. The timed approach flow for four dimensional (4D) flight management system (FMS) equipped aircraft starts at anchor points WP1 and WP2. Each equipped aircraft is given an RTA to its anchor point and another to the final approach fix (FAF).
5. Each 4D equipped aircraft is cleared to merge behind its assigned immediate lead and then to space in trail according to a specific timing criterion.[9]
6. ATM monitors the approach as a string of merging moving slots representing required flow, sequencing, spacing, and landing timing. The slot string re-initializes whenever there is a gap in the arrival flow. Aircraft blundering outside of their slot are taken out of the string and vectored in with the non-equipped aircraft.
7. Non-equipped aircraft merge onto a separate down wind leg and pattern beginning at WP3A and WP3B for later incorporation into the landing flow. They stay in a separate racetrack pattern until they can be absorbed into the landing approach pattern with the equipped aircraft.
8. The approach trajectories are underneath the departure flyways.

A possible arrangement of non-interfering approach and departure airspace corridors for an airport with two parallel runways is shown in Figure 5. In this airspace arrangement:

1. Inbound traffic is timed to anchor point pairs WP1, WP2, WP3 and WP4 for each runway on 12 entry (blue) corridors. Straight in to +30 deg use WP1; 31-60 deg approaches use WP2; 61-90 deg approaches use WP3; 91-180 deg approaches use

WP4. As in Figure 4, each anchor point begins the approach pattern.

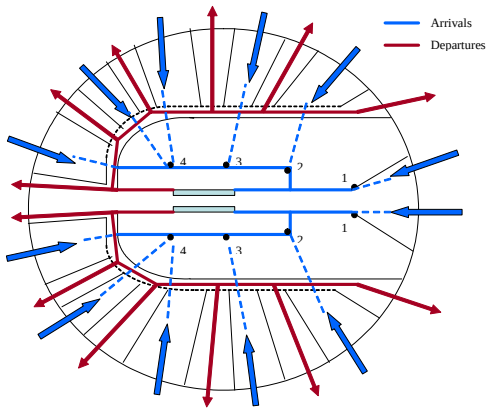

Figure 5 Typical Towered Airport Anchor Point Scheme

2. Departures use 12 evenly spaced departure (red) corridors connected by a U-shaped flyway from the point where the departure path is higher than the approach pattern altitude. They alternate in location with the approach corridors.
3. Departure flyways, corridors and associated trajectories are higher than the associated arrival corridors.
4. If there is no interfering trajectory, each departing aircraft is cleared to its most direct path away from the runway that connects to its intended en route flight plan.

Core Idea 2: Utilize Terminal Area Time-Based ATM

For the PTP concept, a greater number of approach and departure aircraft paths need to be used within the "expanded terminal area." The current design of a Terminal Radar Approach Control (TRACON) primarily supporting large airport operations is expanded in both airspace volume and in complexity of operation. The ATM system provides service to more trajectories flying to/from a more extensive network of airports.

The projected increase in operations to the primary and surrounding airports necessitates a change to the current ATM terminal airspace organization. The current airspace is highly structured around the procedural separation needs of the existing radar-based manual conflict detection and control system. It is highly regimented and generally inflexible during peak periods to more than a few (if any) user requests for specific treatment regarding speeds, shortened paths, descent points, minimal level flight, placement in the sequence, and use of specific runways.

The flight paths through the 2020 terminal airspace are optimized based on cost, efficiency, fuel savings, and airline schedule adherence. In addition, the future terminal area ATM processes are dynamic, to facilitate providing continuing service during disrupting events such as weather fronts, storm cells, missed approaches, runway closures and priority aircraft. Key to this core idea is the harnessing of the ability of the aircraft to fly prescribed 4D trajectories; this concept idea is an extension of the NASA En Route Descent Advisor tool.[10]

The terminal area airspace is defined to extend approximately from the various runway departure points out to where aircraft cross the nominal transition altitude of FL180. This is a composite arc boundary from each airport within the extended terminal area. For arrivals, the terminal area is the extended composite arc distance corresponding to the transitional altitude of 18,000 ft from each set of the airport anchor points served by that terminal area.

A pictorial overview of the expanded terminal area operation is provided in Figure 6.

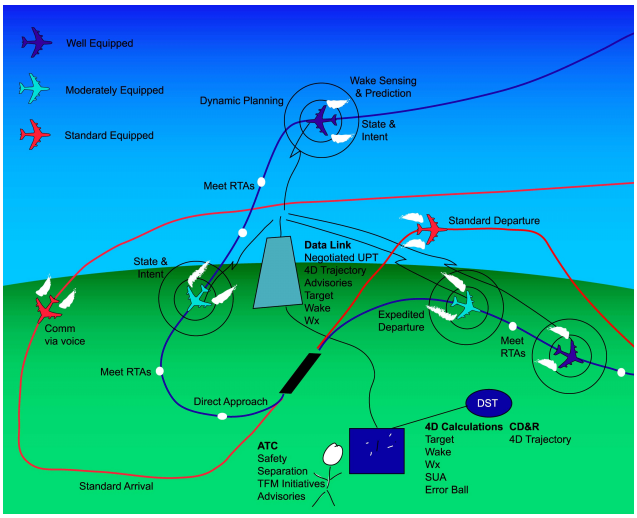

Figure 6. PTP Terminal Area Operations

The increases in regional capacity are facilitated by extensive use of time-based ATM automation for most aircraft coming from and going to the array of airports and runways. This includes the harnessing of ADS-B based separation requirements and flight management system (FMS) 4D guidance.

Collaborative Airspace and Trajectory Planning

The regional TFM function (R-TFM) derives the terminal area "game plan" based upon data from many sources. The R-TFM communicates with each of the airports (towers or non-tower ATM automation functions) in order to process filed flight plans waiting to open (aircraft waiting to depart) and to track both

arrival and departure acceptance rates of each runway in use. Furthermore, the R-TFM unit communicates with the surrounding en route ATM and TFM units in anticipation of and timing of in bound aircraft to each destination airport within the region.

The typical terminal control area four corner post feeder fixes and departure gates are replaced or augmented to include a series of runway configuration dependent anchor points, described earlier and illustrated in Figure 7 for a hypothetical terminal area. Trajectories tied to anchor points require the aircraft to arrive at a waypoint at a specified time and heading. This airspace device is used by the terminal ATM system to impose constraints on the aircraft in maintaining proper separation within the terminal area as well as providing an entry or exit point to a precise arrival/departure path. Incoming aircraft trajectories are coupled to the inbound anchor points by an RTA. Similarly, outgoing aircraft begin their trajectories at other waypoints positioned so that departing aircraft paths do not interfere with arrival trajectories.

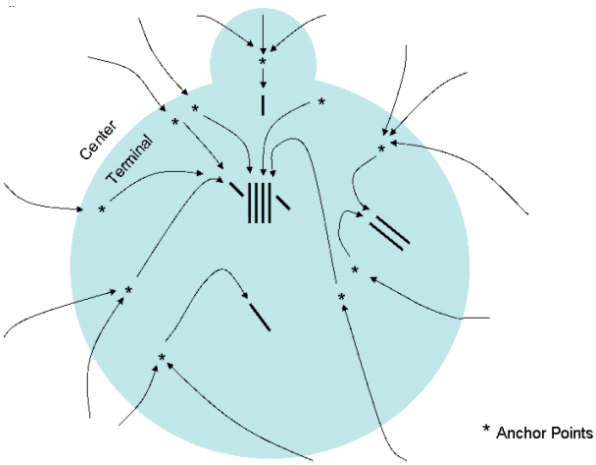

Figure 7. Arrival Paths via Anchor Points

In organizing the automated traffic management process within the expanded terminal area, the first step is to map (a) the airspace constraints; and (b) the ideal trajectories that each flight crew would fly if there were no airspace constraints. The following automation sequence provides this mapping.

a. The forecast wind and temperature fields and any constraining weather cell geometries for the terminal airspace are continually updated. The subset of these data pertinent to a particular aircraft is up-linked to the FMS of that aircraft.

b. Special use airspace (SUA) status and noise abatement procedures status are updated and up-linked if change occurs.

c. For those aircraft applying to enter this airspace, ATM automation accesses the desired aircraft climbing or descending trajectory as communicated via the system wide information management system (SWIM) and emanating from either the aircraft FMS or the fleet operator via the filed flight plan.

d. Each projected flight trajectory is computed sequentially as the intention and knowledge of arrival or departure operation timing is known. These trajectories are first generated as “ideal” without regard to other traffic or weather constraints but accounting for SUA and noise abatement constraints. (The generation process is the same as in the FMS and with identical data so that both ATM and FMS processes produce essentially identical projected trajectories). The computed trajectories are optimal, in the sense that they represent the operator’s or user’s preferred trajectory (UPT) to or from the runway. In addition, the computed projected trajectory information includes its fastest and slowest variations, assuming that the same horizontal path is maintained as the nominal trajectory. This fast/slow information allows computation of available times of arrival at key waypoints (for setting RTAs) along the projected trajectory.

e. Each new arrival trajectory in the set is tested against the airport acceptance rate constraint and runway configuration to verify that flow rate restrictions are not violated, and conformance to planned configuration change is followed. If conformance is violated, the terminal ATM requests the en route ATM to correct the flight arrival time before reaching the terminal boundary.

f. The expected departure trajectory and its timing are tested against TFM initiatives, and are used to project timing at the departure anchor point and the subsequent en route entry point. Again, the terminal ATM provides release approval of the departures to the respective airports to ensure departure rate conformance.

g. A nominal trajectory state envelope (protected airspace zone – PAZ[11]) is defined around each point along the aircraft nominal trajectory, and this includes attachment of the wake vortex airspace volume for the particular aircraft type and atmospheric conditions. One may think of flights within this system as non-conflicting cells (defined by the PAZ) moving along precise four-dimensional (4D) paths, or tubes.

h. The aircraft "nominal sequence" (order of takeoff or landing at each runway) is set or extended based upon both the order that new arrivals and departures request to enter the airspace and the optimal loading of each runway.

i. The nominal trajectories are sequentially processed to determine if any conflict occurs with other traffic PAZ or weather cell constraints. If no constraints are violated, the aircraft is cleared to follow its UPT to the appropriate anchor point or en route entry point.

Weather Cell and PAZ Conflict Resolution

The process of removing trajectory conflicts with either weather cells or other aircraft PAZs involves changing the nominal trajectory though sequential changes to the lateral path, speed profile, vertical path, and initial timing of the trajectory. The steps followed are:

a. Feasible flight corridors are defined for the individual weather-conflicted aircraft that would avoid flight through these weather cells.

b. The weather-conflicted aircraft lateral path is changed to lie within the feasible corridor. Path changes are made to maintain the shortest lengths with acceptable turn numbers.[12]

c. Based upon the new horizontal path, the projected nominal reference trajectory is re-generated to determine its new timing envelope (for computation of waypoint RTAs).

d. The new nominal trajectory and its associated PAZ are next tested with a conflict probe to determine if loss-of-separation conflicts occur with adjacent traffic. If no conflicts occur, the aircraft is cleared to follow the new nominal.

e. If loss of spatial separation is projected to occur, then the trajectory speed profile is next adjusted within the waypoint arrival timing envelopes to determine if the conflict can be avoided by such adjustment. This would produce trajectory constraints such as "arrive at Waypoint X1 <u>at or before</u> Y1 reference clock time". This timing sequence is checked to determine that the resultant trajectory is reasonable from acceleration profile and FMS guidance considerations. This assumes that the ATM system communicates and negotiates with the aircraft FMS, and the aircraft is capable of flying a multiple-RTA trajectory.

f. If the RTA computation conflict resolution method does not provide a viable solution, then the projected trajectory is next adjusted via altitude hold segments. That is, crossing aircraft are assigned different altitudes at the crossing points so that the conflicts are avoided.

g. If an acceptable reference trajectory is not found due to tight spacing constraints, then either the entry time into the terminal airspace is adjusted (by delaying takeoff or entry from the en route airspace), or the flight entry is denied until an acceptable reference trajectory can be found.

h. When a viable reference trajectory is found that avoids conflicts, this is linked to the flight deck FMS for acceptance. The constraints that led to this solution are also up-linked for flight deck review and increase in flight deck situational awareness.

Decreased Separation Management

Key to managing more aircraft in the expanded terminal area is the ability to reduce the separation requirements between aircraft by way of better surveillance and precision guidance, yet still retain the same level of flight safety as today. This improvement is possible by use of ADS-B based upon the precision state estimates provided by GNSS. It remains to determine how much the lateral and vertical separations between terminal area aircraft can be reduced with this technology, but for concept purposes, we assume that aircraft can be laterally and vertically spaced well below the current 3 nmi and 1000 ft limits. The longitudinal separations are going to be dictated by better knowledge of the spatial dimensions of the trailing wake vortices behind each aircraft. The position taken in designing this new traffic management system is that those aircraft that are well equipped enable greater densities of terminal area traffic and will receive optimal routes based upon their desired UPTs.

Two critical factors, aircraft target tracking and wake mapping/tracking are now discussed as they pertain to decreased separation:

<u>Aircraft Target Tracking</u> Parameters that determine the relevance of a conflict include current track location, predicted trajectory uncertainty, tracking technology, aircraft equipment and characteristics, and communication latencies. These factors are used to calculate a Required Total System Performance (RTSP)[13] which affects the size of the PAZ for each aircraft. The PAZ includes the volumetric description of the statistical uncertainty of the aircraft trajectory, as computed within both the FMS and the ATM automation.

By the year 2020, complete terminal airspace surveillance is provided by supplementing SSR with ADS-B and/or multi-lateration. For those aircraft equipped with avionics to provide precise RTSP, and 4D FMS guidance, these capabilities ensure that the lateral and vertical deviations of the climb/descent UPT flight segments are small. These technologies enable closer separations than allowed by today's radar protected airspace by reducing the PAZ.

Wake Tracking As wake avoidance is deemed a critical aspect of compressing the separation technology, to enable tracking or real-time mapping of where the wakes are spatially located behind each aircraft becomes progressively more important.[14] Obtaining measured intensities of wakes for each aircraft type under different weather conditions is the basis for an algorithm for wake tracking and avoidance. Computed mapping of high fidelity wake information can be displayed in the cockpit as well as integrated into the ATM prediction tools.[15]

The wake generated by the aircraft is tracked as an appendage to the aircraft, and it expands the dimension of the PAZ to a boundary where the intensity is weak or the wake reaches the ground. When calculating the separation required for conflict-free trajectories, the ATM automation maintains the wake enclosure as part of the required separation constraint. This information is available to both the ATM system and the flight deck, either by direct computation or via data link, for additional situational awareness and avoidance.

Core Idea 6. Leverage Advanced Aircraft Avionics

The PTP concept leverages advanced aircraft avionics to further increase airspace capacity. Many avionics technologies across the CNS spectrum are used to facilitate the core ideas for traffic management and flight operations. These technologies *are not required* for aircraft to participate in the NAS, but a relatively high level of equipage *is required* for operators to get the full benefit of the PTP concept, and for the concept to accrue its full capacity benefits.

Figure 8 shows the major functional components of the airborne electronics of an advanced aircraft of the future, and indicates the interdependencies of the components. This diagram is not intended to represent the physical connections between the components, but rather a data-flow perspective.

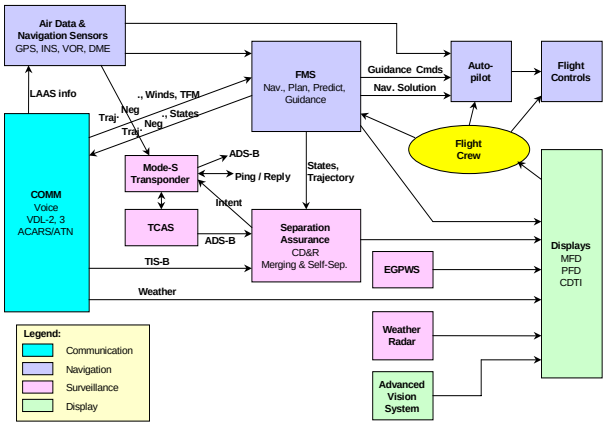

Figure 8. Avionics Functional Relationships

Table 1 summarizes the avionics capabilities and how they are used in the terminal area and airport vicinity.

Table 1. Avionics Capabilities Summary

Capability	Airspace	
	Terminal Area	*Airport Vicinity*
2-way Datalink (CPDLC/ADLS)	Yes, full trajectory negotiation	Yes, uplink of sequence number, spacing reqs, and FAF RTA
Traffic Uplink	Yes, for aircraft without ADS-B	Yes, for aircraft without ADS-B
Weather Uplink	Yes	Yes
ADS-B	Yes	Yes
4D FMS / RTA / Trajectory Negotiation	Yes, RTA at entry point, crossing points, and transition to airport airspace. Trajectory negotiation used as needed.	Yes, RTA at anchor point and/or FAF. No trajectory negotiation.
CDTI / Merging and Self Separation	Yes, for aircraft going to same runway	Yes, to merge behind and follow aircraft, as appropriate
LAAS (Curved App/Dep Paths)	Yes	Yes
WAAS	Yes	Yes
Highway-in-the-Sky	Yes, to track curved app/dep paths	Yes, to track curved app/dep paths
Surface Map Display	N/A	Yes
Wake Vortex Display	Yes	Yes

PTP Capacity Evaluation for LA Basin

In order to start quantitatively assessing the potential impact of the PTP concept, we analyzed the potential capacity improvement from auxiliary airports surrounding a large metropolitan airport. Our initial focal region was the Los Angeles (LA) Basin.

The LA Basin is worthy of study as a future NAS problem for a number of reasons including:

1. Los Angeles International Airport (LAX) is the 4th largest airport in total number of operations/year, is the world's 3rd busiest air cargo airport[16], and has the worst on-time performing airport in the NAS[17];
2. A majority of passengers flying through LAX use it as an origin or destination and not as a point of transfer (therefore, adding a new, remote hub airport will not solve the capacity problem);
3. The LA Basin has a number of the busiest NAS General Aviation airports including Van Nuys/VNY (#1), Long Beach/LGB (#7), Zamperini Field/TOA (#47), Santa Monica Municipal/SMO (#49).[18]

The LAX Demand/Capacity Imbalance

An in-depth analysis into existing NAS airport demand/capacity levels was recently conducted.[19] This analysis suggested that the current demand-to-maximum VFR capacity ratio for LAX is the highest of any NAS airport and equal to 0.77. Given that current demand forecasts[17] predict an increase in LAX demand of 25% in the next 10 years, the current trend points to a near-future LAX gridlock.

To generate a 2020 forecast of LAX demand, we used an April 11, 2002 set of ETMS data and propagated this demand by extrapolating using a FAA Terminal Area Forecast-derived 2.52% annual growth in ops per year. To generate a forecast of future LAX capacity, we assumed that LAX's capacity remains the same as in 2000 based on local[20] and national[21] forecasts that no new major runway constructions are planned. Therefore, under VFR conditions, the optimum hourly arrival rate is 84 and the optimum hourly departure rate is 64.[17]

To quantify the expected impact of the future 2020 demand and capacity imbalance, we constructed a LAX Deterministic Delay Diagram (DDD) to estimate the impact of the excessive demand over the typical day. The DDD is a variant of generic queuing diagram.[22] Time is represented in the x-axis of the delay diagram and number of flight operations is represented in the y-axis. The DDD consists of two curves: one represents the cumulative number of flights that are scheduled to use the airport, the second represents the total number of flights the airport handled.

This cumulative throughput at time i can be represented as:

$$CT_i = min\ (CSF_{i-1} + \Delta,\ CT_{i-1} + \Delta),$$

where:

$$\Delta = min\ (SF_i,\ AT_i),$$

CT_i = Cumulative Throughput at time i;
CSF_{i-1} = Cumulative Scheduled Flights at time i-1;
SF_i = Scheduled Flights at time i;
AT_i = Airport Throughput at time i.

Therefore, the Cumulative Throughput curve is always less than or equals to the Cumulative Scheduled Flight curve. Also, the slope of Cumulative Throughput at time i is either SF_i/time unit or AT_i/time unit. The area between the Cumulative Throughput curve and the Cumulative Scheduled Flights curve is the deterministic delay. The deterministic delay only accounts for the delay between the scheduled flight demand and the theoretical airport throughput.

Figure 9 shows 2002 and 2020 LAX total operations DDD. As expected, the average deterministic delay for 2002 operations at LAX is only 0.21 minutes per flight. However, the deterministic delay increases dramatically to 24 minutes per flight for the demand level in 2020. Note that these delays build up even under the assumed all-day good-weather visual meteorological conditions (VMC).

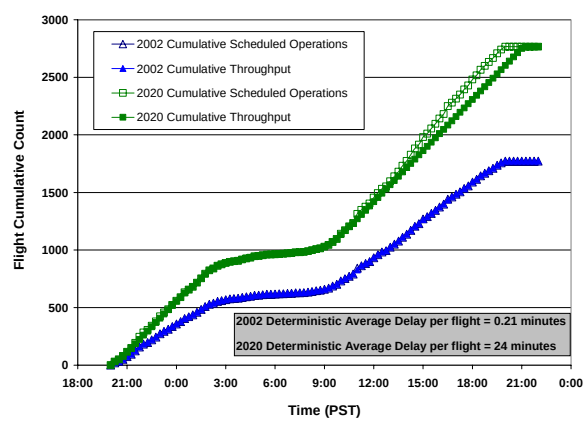

Figure 9. A Deterministic Delay Diagram for 2002 and 2020 LAX Operations

The LA Basin Demand/Capacity Imbalance

In addition to LAX, there are a number of LA Basin airports within the 30 nm LAX Mode C Veil that currently or theoretically could support future commercial service. The 11 public-use airports are listed in Table 2. Four of them currently provide commercial service: LAX, BUR, LGB, and TOA. Other private use airports do exist in the region such as Goodyear Blimp Base (64GL), Los Alamitos AAF (SLI), Shepherd Field (CA42), and a high density of local private heliports exist: 44 are within 10 nm of LAX.

For each of the 11 LA Basin airports, we first determined the average number of 2000 operations per day by taking the FAA's TAF values of total annual airport operations and dividing them by 360. Then, we extrapolated to obtain the number of 2020 operations by using a calculated average annualized growth factor derived from the Year 2000 and 2015 TAF predictions.

Predicting capacity for these 11 airports was more difficult. Unlike high-profile, hub airports, like LAX, detailed capacity information on the other 10 LA Basin airports is not readily available. Because of this, a reliable capacity estimation method for these other airports was needed to quantify the available LA Basin capacity. Two readily-available methods investigated were:

1. Method I - FAA handbook approach[23];
2. Method II – LMI Capacity study[24].

Both methods were analyzed to estimate existing LA Basin capacity. We concluded that Method I provides more realistic capacity prediction results than Method II, based on comparing their predictions to TAF airport operations data. In the cases of LAX and VNY, Method II provided estimates that significantly under predicted the observed Year 2000 throughput. One potential reason for this is Method II's lack of incorporating fleet mix into its capacity prediction methodology. According to Reference 23, fleet mix is a significant factor that can vary single runway, VFR capacity by over a factor of 2.

Utilizing Method I, we used the VFR and IFR capacity predictions for each airport and came up with a "daily average capacity" (shown in Table A) that weighted the VFR/IFR capacity based on estimated frequency of IMC conditions.

Then, the airport-specific predicted demand and capacity data were compared in demand-to-capacity ratio and an excess demand per day (i.e., demand-capacity) statistics. The results of this simple analysis are shown in Table 2.

Analysis of the TAF-based demand predictions yields some interesting observations. First of all, LAX, the airport with the highest Year 2000 number of operations, is expected to have the greatest demand increase in 20 years: an increase in ops by 65%. The next airports with the highest expected demand increase are the other airports which provide commercial service: BUR, LGB, and TOA. All the other LA Basin airports show more moderate demand increases, except for CPM, HHR, and FUL which expect no traffic growth.

To analyze the forecasted LA Basin airport demand/capacity imbalance, we assumed that all flights are created equal and one could fill each of the airports with additional flights up to maximum airport capacity. The results in Table 2 show that despite LAX being nominally overloaded, there exists enough runway capacity in the other LA Basin airports to more than handle the expected nominal 2020 demand loading. In fact, there is enough runway capacity in the LA Basin airports to handle ~6900 additional flights for an equivalent future demand-to-capacity ratio of 0.61 (significantly less than the 2000 LAX ratio).

Despite the simplifying assumptions, these very preliminary results suggest that for one of the most demanding NAS capacity problems, a potential solution exists in increased usage of the existing public use airport network. This increased usage of the surrounding airports will be enabled through advanced ATM concepts such as the previously-explained Concept PTP.

Table 2. 2020 LA Basin Airport Demand/Capacity Imbalance Predictions

Airport ID	Average Ops per Day in 2000*	Forecast Average Ops per Day in 2020†	Daily VFR Average Capacity‡	2020 Demand/ Capacity Ratio	2020 Excess Demand per Day
LAX	*2171*	*3578*	*2858*	*1.25*	*720*
HHR	*221*	*215*	*1143*	*0.19*	*-928*
SMO	*535*	*620*	*991*	*0.63*	*-371*
CPM	*167*	*167*	*2178*	*0.08*	*-2011*
TOA	*515*	*683*	*1780*	*0.38*	*-1097*
LGB	*1148*	*1770*	*2300*	*0.77*	*-530*
BUR	*452*	*583*	*1175*	*0.50*	*-592*
VNY	*1465*	*1739*	*1980*	*0.88*	*-241*
WHP	*395*	*442*	*1143*	*0.39*	*-701*
EMT	*452*	*596*	*991*	*0.60*	*-395*
FUL	*258*	*237*	*991*	*0.24*	*-754*
Total LA Basin	***7779***	***10630***	***17530***	***0.61***	***-6900***

* Based on Reference 18.

† Assumes extrapolation to 2020 based on constant growth rate derived from Year 2000 and 2015 data.

‡ Using the previous results of Capacity prediction Method I.[23]

Summary and Conclusions

This work formulates a new air transportation concept that makes massive use of point-to-point operations between the many available public U.S. airports (under utilized today) to enable increasing the NAS payload capacity by a factor of 100% or more within the next twenty years. The PTP concept consists of six integrated, core ideas. It employs extensive use of ATM automation, particularly for non-towered airports, and it harnesses the ability of the FMS to guide aircraft along precise 4D trajectories with multiple RTA waypoints. A summary is provided of the features of the core ideas covering the airport vicinity, the extended regional terminal area, and the advanced flight deck. Furthermore, the preliminary results of applying this concept to solving the projected capacity bottleneck for the Los Angeles basin in year 2020 are presented. We conclude that there is ample existing airport and runway availability to service the anticipated need in capacity growth for that time period.

Acknowledgement

The authors acknowledge the NASA Ames Research Center's VAMS project for funding this research. The authors thank Dr. Karl Bilimoria of NASA, Dr. Paul Abramson, Dr. Edward Koenke, and Capt. Rob Fuschino of UAL for providing us constructive concept feedback.

References

1. Anon, Department of Transportation, February 2001, "FY2001 Performance Report;" Washington, DC. http://www.dot.gov/performance/pdf/complete.pdf
2. Anon, FAA, 2001, "2002 Aerospace Forecast," Washington, DC.
3. Anon., FAA, April 2001, "Operational Evolution Plan, Version 4.0, Washington, DC.
4. Holmes, B., Oct. 2001, "Small Aircraft Transportation System Program," NASA Langley Research Center, Hampton, VA.
5. Sorensen, J., et al., Jan. 2003, "Massive Point-to-Point (PTP) and On-Demand Air Transportation System Concept Description," TR 03231-01, Seagull Technology, Inc., Campbell, CA.
6. Koenke, E., and Zellweger, D., July 1976, "A Description of the Automated Terminal Services Concept," FAA EM-76-6, Washington, DC.
7. Schleicher, David R., et al., "Smart Airport Automation SYstem (SAASY) Phase II SBIR Final Report," TR02214-01, NASA Contract No. NAS2-01017, Seagull Technology, Inc., Campbell, California, December 2002.
8. Conway, S., and Consiglio, M., "A Method of Separation Assurance for Instrument Flight Procedures At Non-Radar Airports," AIAA 2002-4448, August 2002.
9. Oseguera-Lohr, R., et al, Oct. 2002, "Evaluation of Operational Procedures for Using a Time-Based Airborne Inter-Arrival Spacing Tool," AIAA ATIO Conf., Los Angeles, CA.
10. Green, S. M., and R. A. Vivona, Aug 2001, *En route Descent Advisor Concept for Arrival Metering*, AIAA 2001-4114, Montreal, Canada.
11. Ennis, R., and Zhao, Y., Nov. 2003, "Characterization of Aircraft Protected Zones," to appear, AIAA ATIO Conf., Denver, CO.
12. Krozel, J., May 2000, "Hazard Weather Avoidance for Air Traffic Control Systems," NASA SBIR Phase II Final Report, TR98174-01, Seagull Technology, Inc., Los Gatos, CA.
13. Shakarian, A., et al, Nov. 2002, "An Emerging ATM System Performance Measurement Index: Required Total System Performance," 47th Annual Air Traffic Control Association Conf., Washington, DC.
14. Bryant, W., 2000, "Avoiding Rock and Roll – Aircraft Vortex Spacing System," NASA Langley Research Center, Hampton, VA.
15. Holforty, W., and Powell, D., Oct. 2001, "Flight Deck Display of Airborne Traffic Wake Vortices," 20th DASC Conf., Daytona Beach, FL.
16. Anon., ACI, 2001, http://www.airports.org, "Airport Council International 2000 Traffic Data", Washington, DC.
17. Anon., FAA, 2002, "Airport Capacity Benchmark 2001," Washington, DC.
18. Anon., FAA, Dec. 2001, "Terminal Area Forecast Fiscal Years 2001-2015," FAA-APO-00-7, Washington, DC.
19. Welch, J., and Lloyd, R., Dec. 2001, "Estimating Airport System Delay Performance," 4th USA/Europe Air Traffic Management R&D Seminar, Santa Fe, New Mexico.
20. Anon., 2001, "Los Angeles International Airport Master Plan," http://www.laxmasterplan.org/
21. Anon., FAA, 2001, "Airport Capacity Enhancement Plan," Washington, DC.
22. Hansen, M., Tsao, J., Huang, A., and Wei. W., Jan. 1999, "Empirical Analysis of Airport Capacity Enhancement Impacts: A Case Study of DFW," TRB #991444, Washington D.C.
23. Anon., FAA Office of Airport Safety and Standards, Feb. 1997, "Airport Design", Advisory Circular 150/5300-13, Change 5, Appendix 16, Washington, DC.
24. Johnson, Jesse, et al., June 2002, "Future Air Transportation System Definition," Logistics Management Institute, Washington, DC.