REDESIGNING THE NATIONAL AIRSPACE SYSTEM FOR SUSTAINABILITY

Summer Task Force on Air Transportation
Princeton University, Princeton, NJ
Sponsored by
FAA/NASA Joint University Program for Air Transportation
December 9, 2004

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FOREWORD

During the summer of 2004, a task force comprised of three Princeton University engineering students conducted an independent assessment of technologies and policies for the U. S. National Airspace System (NAS). Their objective was to guide future investments and improvements in the NAS. The task force identified choke points that impede air travel, highlighted system requirements for safety, security, economy, and efficiency, and recommended policy decisions for NAS stakeholders. The task force considered air traffic management, communication, navigation, and surveillance, security, meteorological effects and reporting, network and regional airline operations, general aviation operations, airport operations, and interfaces with ground transportation, as well as social and economic benefits of air transportation for the country.

The students had no prior knowledge of air traffic control or airline operations, but they had strong technical backgrounds and developed remarkable insights in a short period of time. John Andrews is a member of the Class of 2005 and is majoring in Operations Research and Financial Engineering. Ezekiel Burke, Class of 2004, received his BSE degree in Mechanical and Aerospace Engineering (MAE) in June. John Thomas is a member of the Class of 2005 and is majoring in Mechanical and Aerospace Engineering.

From beginning to end, the project took 10 weeks. During the fact-finding phase, team members reviewed background documents and reports and were briefed by senior staff and policymakers from FAA, NASA, MITRE, jetBlue, NBAA, and by an industry consultant. During the integrative phase, team members assembled and interpreted information. In the reporting phase, the students prepared a written report that contained their findings and recommendations, suggesting specific targets for investment by the government and industry. They presented their findings at the Quarterly Review of the FAA/NASA Joint University Program on Air Transportation, which was held at the Massachusetts Institute of Technology, October 7, 2004.

Prof. Luigi Martinelli (MAE), Dr. Joseph Michels (Director for Research Initiatives, Princeton Institute for the Science and Technology of Materials), Prof. Robert Stengel (MAE), and graduate student Arron Melvin (MAE) provided advice, guidance, and technical support for conduct of the project and preparation of the final report. The study was supported by the FAA/NASA Joint University Program for Air Transportation under FAA Grant 95-G-011. The MITRE Corporation provided travel support for a 2-day fact- finding trip to Washington, DC. The report is the original work and reflects the findings of the three student authors, who made all final decisions on the report's content.

The report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review was to provide candid and critical comments that would assist in making the published report as sound as possible. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for reviewing this report:

Charles Draper, National Research Council
Sandeep Mulgund, The MITRE Corporation
John Olcott, General Aero Company
Michael Paglione, Federal Aviation Administration
Glenn Roberts, The MITRE Corporation
Banavar Sridhar, National Aeronautics and Space Administration
John Wangermann, Mercer Management Consultants
Craig Wanke, The MITRE Corporation

The reviewers provided many constructive comments; they were not asked to endorse the report's conclusions and recommendations, and they did not see the final draft prior to its release. Responsibility for the contents of the report rests with its authors and their advisors.

CONTENTS

EXECUTIVE SUMMARY

The United States' National Airspace System (NAS) is incapable of sustaining the scale of operations foreseen in the immediate future. It is barely capable of sustaining today's level of operations. With American civil aviation itself comprising 11 million jobs and generating almost one-tenth of the Gross Domestic Product, and because enabling the mobility of the nation's citizenry and goods is vital to the American economy, the United States must meet the physical, technological, and conceptual challenges of preparing the NAS for the Twenty-first Century.

The summer of 2000 brought unprecedented delays due to high volumes of flights compounded by a season of inclement weather, with delays affecting one fourth of all flights. After a temporary decrease in operations due to the 9/11 attacks and economic recession, traffic levels have rebounded and continue to rise. The Administrator of the Federal Aviation Administration (FAA) wrote in June that "by the end of 2004, we expect a return to pre-9/11 operating levels at 15 major airports, including seven of the top ten." In late 2001, the FAA predicted that by 2010, enplanements would increase by over 40 percent, and the number of airliner-operated aircraft by over 50 percent of then- current levels. Deliberate measures are required to accommodate this predicted dramatic increase in traffic.

Although current efforts are steps in the right direction, they are insufficient to solve the present and future shortage of capacity. Attempts to alleviate airspace congestion include the reduced vertical separation minima (RVSM), to be implemented in January 2005, negotiation of voluntary reductions in scheduled service, and the construction of additional runways at major airports, many of which are far behind schedule in construction. These steps are the most obvious, immediate remedies at hand. More fundamental changes are needed, however, in order to ensure sustainability.

MAJOR ISSUES IN REDESIGNING FOR SUSTAINABILITY

The existence of a capacity shortage naturally prompts the following lines of inquiry. These lines of inquiry respectively form the three chapters of our report.

1. How and why does existing infrastructure constrain the scale of NAS operations?
   - Where are the "choke points" causing NAS congestion?
   - Are there cost-beneficial means of expanding existing infrastructure at these points?
   - What existing infrastructure is currently underutilized and why?
   - How can underutilized segments of the infrastructure be better integrated into the NAS?
   - How can the NAS be better integrated with other modes of transportation?
2. Why does demand exceed the capabilities of the existing infrastructure?
   - How can artificial price ceilings on NAS usage be eliminated, allowing market pricing to allocate usage to highest value?
   - What would such pricing look like if applied to existing cost structures?
   - How does the current regulatory environment impact airspace efficiency?
3. How can congested NAS resources be managed more efficiently?

- How can enhanced information distribution assure that NAS users have access to timely, pertinent information in order to effectively engage in Collaborative Decision Making (CDM) as well as situational optimization?
- How can technological advances enable each operation to use a smaller area of the NAS?
- What conceptual advances in traffic management might enable operations to use the NAS in new procedural standards, particularly to avoid severe weather, a compounding factor of congestion?

APPROACH

For ten weeks, we the members of a Summer Task Force under the FAA/NASA Joint University Program in Air Transportation consisting of three undergraduates, three faculty and staff advisors, and one graduate student advisor, explored these major questions through field trips and research. We present our findings in this paper. The program is sponsored by the FAA and NASA.

The brief span of our project confines us to the above lines of inquiry. We recognize that other threats to the sustainability of the NAS, specifically the threat of terrorist attack, exist and present additional challenges beyond the scope of this report.

SUMMARY OF FINDINGS

Congestion plaguing the NAS is a function of quantity of demand, amount of existing capacity, and uncertainty of access to capacity (e.g., during inclement weather). This congestion, via applicable standards of safe operation, causes delay. Capacity shortage and inefficient allocation of existing capacity limit the scope of currently sustainable operations. The efficiency of these operations is limited by compartmentalized information, obsolete technology, and bureaucratic entrenchment opposing modernized operating procedures at every level of the aviation community. The following major difficulties are associated with infrastructural, regulatory, technological, and procedural advancement:

- Whereas major airports are faced with excess demand and heavy congestion, existing capacity is underutilized at many regional airports.
  - Operators lack incentives to align their operations with existing capacity because they are not required to pay for the value of the resources they consume, nor are they held accountable for the negative externalities they generate.
  - Further development of regional airports is resisted by residential and environmental interests and limited by degree of access to major population centers.
  - Consumers lack comparative information to effectively utilize regional airports and connecting infrastructure and to determine whether other transportation methods in lieu of or in conjunction with air transportation are more efficient.
- Current procedures for routing aircraft at the en route level of traffic control, including distance-based separation standards and procedures for merging traffic flows, are relics from the days of pre-deregulation traffic levels, two-dimensional radar-based paradigms, and now-obsolete navigation technology, artifacts whose continued use results in inefficient consumption of the NAS.

  - Many aircraft are not equipped with the latest avionics and redesigned procedures must be sufficiently robust to accommodate operators with widely varying sophistication of equipment.
  - In order for redesigned procedures to be effective, operators must be convinced that the costs of upgrading to take advantage of redesigned procedures are outweighed by the benefits.
  - En-route control centers are not universally equipped to accommodate hi- tech operators by providing more efficient routing directions.

- Other concerns include the NAS's need for updated equipment, response procedures, and other general policies stifle potential improvements to the system.
  - The ultimate benefits of digital avionics will be realized in a network for automatic information exchange, but no platform yet exists.
  - The NAS does not respond quickly to improvements in weather conditions, perpetuating weather-related congestion and delays.
  - Mandatory retirement regulations are removing a critical number of controllers from the NAS in the immediate future.

ELABORATION OF RECOMMENDATIONS

We recommend that the following be implemented within three years:

- **Reform FAA operations tax.** Current prices of Air Traffic Control (ATC) for passenger and cargo operations, consisting of flat-percentage rates on ticket fares and transportation fees, are distorted by aircraft size, load factor, connecting status of flight, and carrier's business model, and rates are insensitive to time- and location-variant demand. This price distortion causes inefficient allocation of scarce airspace. We recommend that the FAA adopt one tax system for all commercial operations and that operators themselves (not passengers) be taxed on a per-plane, per-time, per-location basis. The resultant increase in revenues should be directed towards research and development and towards increasing capacity.

- **Extend mandatory retirement age for air traffic controllers.** Because most air traffic controllers were hired after the illegal PATCO (Professional Air Traffic Controllers' Organization) strike of 1981, many air traffic controllers are now close to the mandatory retirement age of 56 years. Because it would be difficult to hire and train enough new controllers in time, and since these controllers are largely willing and able to continue work professional pilots themselves are not required to retire until age 60 we recommend that the federal government temporarily extend the mandatory ATC retirement age by several years. The extension would also buy time to develop and implement new traffic management procedures so that newly hired employees could be trained in the new procedures, circumventing institutional resistance.

- **Increase consumer awareness of alternatives to major airports.** The general public often assumes that commercial travel from a major airport is the fastest or most cost-effective means available. However, taking into account total time spent in travel, many popular commercial routes average less than one hundred miles per hour. The Department of Transportation

(DOT) already reports information comparing the performance and customer service of major airlines, airports, and routes; we recommend that this information also be offered in the context of alternative means of transportation where available, e.g., railways, roads, and general aviation.

- **Support research and development for Vertical/Short Take-Off and Landing (V/STOL) airplanes and seaplanes.** These aircraft have potential in revamping the NAS's infrastructure, but not as they exist today. Research and development programs in these aircraft are necessary so that this technology may someday be utilized.

  We believe that the following recommendations can and should be implemented within the next ten years:

- **Deregulate landing fees.** Landing fees are limited by local and municipal regulations, artificial price controls on airport operations that create excess demand for use of major airports. Delay pricing, a much less desirable form of pricing laden with negative externalities, arises from this shortage. The federal government should leverage existing subsidies, including airport improvement funding and tax exemptions, to deregulate landing fees at the thirty-one major airports, deregulation both in scale (the amount an airport charges the operator) and structure (to a per-plane, not a per-pound, price structure). Any short-term increase in revenue should be directed towards improving capacity and technology.

- **Eliminate slot control.** If above regulatory reforms are adopted, slot control will no longer be necessary. Slot control is undesirable as an allocation system because of aggregation risk, which further artificially depresses the price of operations, and because it erects barriers to new entrants, preventing competition.

- **Lift DOT code-sharing restrictions.** The DOT currently imposes an irrational restriction on the number of code-shared flights between hubs controlled by different carriers. Since code-sharing does not legally allow price- or output- coordination, this restriction is demonstrably detrimental to the consumer, who stands to benefit from the wider range of destinations and lower fares historically resulting from code-sharing.

- **Relax restrictions on foreign ownership of domestic operators.** As many airlines are on the brink of bankruptcy, a protectionist 25 percent cap on foreign ownership is an undesirable restriction on investment in domestic airlines. This restriction should be relaxed to 49 percent in the intermediate range, but long- term negotiations to ensure the reciprocal ability for American investors to own foreign domestic operators are needed before foreign-owned operators should be allowed fifth-freedom (i.e., US domestic) operations.

- **Incentivize use of regional/General Aviation (GA) airports.** A large number of under-utilized runways exist in populated areas served by regional and GA airports. This additional concrete should be utilized as much as possible by commercial aviation services. Care should be taken to address landowners' concerns about commercialization of these airports. Starting soundproofing projects and regulating airplane emissions will help ease local concerns.

- **Adapt runways/taxiways for simultaneous Vertical/Short Takeoff and Landing V/STOL uses.** Large runways can potentially be treated as consecutive smaller runways to enable simultaneous landing and take-off of aircraft that require less runway length, such as STOL airplanes. Researchers should study whether or not this possibility is feasible. If V/STOL prove beneficial, airports should update taxiways and other infrastructure to accommodate this method of runway usage. Furthermore, airports should consider adding supporting ″vertiport″ infrastructure to alleviate commuter traffic at the main airport.

- **Develop ground transportation support services.** Improving access to other forms of transportation will distribute air traffic congestion across alternative methods of transportation. Encouraging the creation of added ground transportation infrastructure will allow ground transportation operators to offer more alternatives to consumers. Eliminating regulatory barriers preventing airlines from owning feeder infrastructure (e.g., light rail) will allow airports farther from population centers to serve a greater portion of the public, reducing road congestion and encouraging airport expansion because airport expansion is less feasible in densely populated areas.

- **Create procedures and incentives for formation flight.** Optional formation flight procedures, where pilots can use visual self-separation or collision- avoidance automation, would enhance airspace efficiency by fitting multiple planes within one zone of separation. En-route controllers would benefit from the procedure's consolidation of the units that must be controlled. Operators would benefit from increased fuel economy and additional incentives in the form of tax breaks on operations.

- **Continue research to advance weather forecasting and improve responsiveness of weather avoidance procedures.** Weather is the most significant source of delay, and the effectiveness with which the FAA responds to changes in weather can compound the problem, often allowing weather-related restrictions to overrun their usefulness. Researching advanced forecasting products and the procedures using weather technology to come up with an effective response should be continued. Ground Delay Programs (GDP) should be evaluated according to their effectiveness and timing, paying special attention to the value of increased communication between controllers and pilots and the widespread distribution of weather information.

- **Install displays integrating all sources of flight and environment information at control facilities.** The transition to a direct routing paradigm is unsustainable by current, manual methods and controller acceptance. New controllers should be trained to use a semi-automated system, which integrates flight data and surveillance data on a common display, incorporates digital communication between the pilot and controller, and uses automated aids to predict potential conflict and track aircraft conformance to intended flight path. The necessary technology to gather this data will also need to be developed. This automation will support the transition to direct-routing, use of more precise navigation and surveillance technology, and increase traffic control efficiency. System-wide implementation of User Request Evaluation Tool (URET) is the first step in the transition to a digital, semi-automated air traffic control system. URET should be installed at all en-route control centers.

- **Develop direct routing systems for all control facilities.** Access to at-capacity routes based on a decades-old navigation system, where traffic is funneled along well-defined routes and over ground-based navigational aids, is highly restricted during severe weather. The FAA should continue to develop procedures to allow aircraft to use arbitrary, direct routes connecting departure and destination to bypass these congested routes and connections. Aircraft flying directly will also save time and fuel. The use of direct routing procedures should replace the current routing system as the primary routing system in the next decade.

- **Develop augmented Global Positioning System (GPS) routing procedures at all control facilities.** Operating and repairing ground-based navigation aids is a financial burden on the FAA. Aircraft must be equipped with GPS technology to use advanced surveillance technology and to communicate 4-D flight data latitude, longitude, altitude, and time over digital data links, a capability necessary for increased situational awareness and automated ATC. Augmented GPS usage should be certified nationwide, and the FAA should develop procedures specific to GPS equipped aircraft.

- **Re-evaluate required separation standards.** The transition to new navigation and surveillance technologies allows for reductions in safe separation standards, particularly in transoceanic routes not controlled by radar. The FAA should continue development of advanced procedures, including reduced separation standards that are available to aircraft meeting navigation and surveillance standards, not only varying by flight phasing.

- **Incentivize operator equipage of Automatic Dependent Surveillance- Broadcast (ADS-B) system.** ADS mitigates the capacity-reducing effect of weather, the largest cause of delay by allowing pilots and controllers to behave as if visibility were high. ADS-B technology also facilitates the implementation of other important modernization concepts, such as direct routing and enhanced situational awareness for pilots, and ADS will increase the safety of the NAS. The FAA should develop and certify procedures that take full advantage of ADS-B equipped aircraft in every phase of flight.

- **Build a national platform for "data link" information exchange.** Voice communication dependent on Very High Frequency (VHF) radio waves is unsafe, slow, and cannot support a significant increase in demand on communication. Eventually replacing this communication infrastructure will permit widespread tactical information distribution and automated routine tasks. Digital data link will also support a safer NAS. The FAA should install the necessary infrastructure to support a digital data link. We believe that the following recommendations can and should be implemented in the less immediate future:

- **Negotiate reciprocal treaties permitting fifth-freedom commercial operations.** The last major anti-competitive airline regulation surviving the 1978 deregulation forbids foreign-owned carriers from providing domestic American service. Unilateral deregulation, however, would disadvantage American carriers, who would still be unable to compete in fifth-freedom (i.e., point-to-point within a foreign country) routes. Therefore, US trade representatives should pursue bilateral or multilateral fifth-freedom agreements. The possibility of fifth- freedom flights lifts constraints upon the optimality of commercial operators' transportation networks.

- **Construct new runways where needed.** Adding runways to the nation's most congested airports will increase the capacity in the NAS. Lack of runway space at the most congested airports is a major chokepoint of the hub-and-spoke system.

- **Create a comprehensive V/STOL infrastructure.** Assuming V/STOL aircraft are proven beneficial, airports should invest in vertiports to increase commuter flights. A vertiport in the vicinity of the main airport would service additional traffic without causing as much stress on the system, due to the vertiport's remoteness from the main runways as well as the nature of VTOL flight capabilities. Airports should also invest in STOL runways whenever possible. Shorter than traditional runways, STOL runways are less expensive and less detrimental to the environment.

- **Develop distributed decision-making technology and procedures.** Although collaborative decision making currently exists at the most strategic level via ATC Command Center teleconferencing in response to large-scale changes of NAS constraints, the long-term goal of distributed decision-making will allow tactical responses at the operator level to small-scale constraint changes and thus a highly efficient NAS use. Such decision-making will only be possible with digital avionics and communication networks and will require new procedures.

CONCLUDING OBSERVATIONS, AND ONE LAST RECOMMENDATION

In investigating NAS sustainability, we are impressed by the quality and quantity of intellect devoted to averting the air transportation crisis our country now faces. We are confident that, in accordance with historical patterns of growth, the products of American ingenuity will overcome these national growing pains, themselves indicators of a healthy economy, and produce yet-unforeseen benefits to the nation.

Just as flight has always fascinated mankind, NAS policy is a subject about which nearly everyone has strong convictions. Because modern air travel is both a commonplace miracle and a near-universal ordeal, and because a healthy NAS is crucial to the vitality of the entire country, every American is a stakeholder in the NAS and is entitled to his convictions. An explicit formulation of a National Airspace System Policy would serve to form consensus among these varying opinions and establish a common set of purposes and priorities for the NAS. Such a mission statement would help define solutions to major challenges in redesigning the NAS for stability, including contentious questions concerning labor relations, anti-trust regulations, international trade, taxation, and funding priorities for research and development. We recommend that the FAA submit such a statement, soliciting input from all stake-holders, including representatives from the military, airlines and cargo carriers, business aviation, general aviation, consumer advocacy groups, and labor organizations.

INTRODUCTION

The United States' National Airspace System (NAS) is incapable of sustaining the scale of operations foreseen in the immediate future. It is scarcely capable of sustaining today's level of operations. Because American civil aviation itself comprises 11 million jobs and almost one-tenth of Gross Domestic Product, and because enabling the mobility of the nation's citizenry and goods is vital to the American economy, the United States must meet the physical, technological, and conceptual challenges of preparing the NAS for the twenty-first century.

The summer of 2000 brought unprecedented delays due to high volumes of flights compounded by a season of inclement weather, delays affecting one fourth of all flights. After a temporary decrease in operations due to the 9/11 attacks and economic recession, traffic levels have rebounded and continue to rise. The Administrator of the Federal Aviation Administration (FAA) wrote in June that "by the end of 2004, we expect a return to pre-9/11 operating levels at 15 major airports, including seven of the top ten." In late 2001, the FAA predicted that, by 2010, enplanements would increase by over 40 percent, and the number of airliner-operated aircraft by over 50 percent of then-current levels. Concerted measures are required to accommodate this dramatic increase in traffic.

Though efforts now underway are steps in the right direction, they are insufficient to solve the present and future shortage of capacity. Attempts to alleviate airspace congestion include the reduced vertical separation minima (RVSM), to be implemented in January 2005, negotiation of voluntary reductions in scheduled service, and the construction of additional runways at major airports, of which many are far behind schedule in construction. These steps are the most obvious, immediate remedies at hand. However, more radical measures are needed in order to ensure sustainability.

MAJOR ISSUES IN REDESIGNING FOR SUSTAINABILITY

The existence of a capacity shortage prompts the following questions:

- How and why does existing infrastructure constrain the scale of NAS operations?
  - That is, where are the "choke points" causing NAS congestion?
  - Are there cost-beneficial means of expanding existing infrastructure at these points?
  - What existing infrastructure is currently underutilized, and why?
  - How can underutilized parts of the infrastructure be better integrated into the NAS?
  - How can the NAS be better integrated with other modes of transportation?
- Why is there excess demand for the use of existing infrastructure?
  - How can artificial price ceilings on NAS usage be eliminated, allowing market pricing to allocate usage to highest value?
  - What would such pricing look like if applied to existing cost structures?
  - How does the current regulatory environment impact airspace efficiency?
- How can congested NAS resources be managed more efficiently?
  - How can enhanced information distribution assure that NAS users have access to timely, pertinent information in order to effectively engage in Collaborative Decision Making (CDM) as well as situational optimization?

– How can technological advances enable each operation to use a smaller area of the NAS?
– What conceptual advances in traffic management might enable operations to use the NAS in new procedural standards, particularly to avoid severe weather, a compounding factor of congestion?

Another serious challenge is the task of protecting NAS stakeholders from terrorist attacks. While security is critical to sustainability, this challenge is beyond the scope of our report.

INTENTIONS AND METHODOLOGY

For ten weeks, we members of a new project under the FAA/NASA Joint University Program (JUP) in Air Transportation, a Summer Task Force consisting of three undergraduates working with faculty and graduate student advisors, explored these major questions through field trips and readings. After a preliminary four week phase of information gathering, we identified chokepoints and other restrictions to NAS capacity. With this knowledge, we continued our study by researching these problem areas, identifying potential solutions and methods of increasing NAS capacity. We present our findings in this paper.

SUMMARY OF FINDINGS

The congestion plaguing the NAS is a function of quantity of demand, amount of existing capacity, and uncertainty of access to capacity (e.g., during inclement weather). This congestion, via applicable standards of safe operation, causes delay. Capacity shortage and inefficient allocation of existing capacity both limit the scope of currently sustainable operations. The efficiency of these operations is limited by compartmentalized information, obsolete technology, and bureaucratic entrenchment opposing modernized operating procedures.
The following major difficulties are associated with infrastructural, regulatory, technological, and procedural advancement:

- Whereas major airports are faced with excess demand and heavy congestion, existing capacity is underutilized at many regional airports.
  – Operators lack incentives to align their operations with existing capacity because they are not required to pay for the value of the resources they consume, nor are they held accountable for the negative externalities they generate.
  – Further development of regional airports is resisted by residential and environmental interests and limited by degree of access to major population centers.
  – Consumers lack comparative information to effectively utilize regional airports and connecting infrastructure and to determine whether other transportation methods in lieu of or in conjunction with air transportation are more efficient.
- Current procedures for routing aircraft at the en route level of traffic control, including distance-based separation standards and procedures for merging traffic flows, are relics from the days of pre-deregulation traffic levels, two-dimensional radar-based paradigms, and now-obsolete navigation technology, artifacts whose continued use results in inefficient consumption of the NAS.

  - Many aircraft are not equipped with the latest avionics, however, and redesigned procedures must be sufficiently robust to accommodate operators with widely varying sophistication of equipment.
  - In order for redesigned procedures to be effective, operators must be convinced that the costs of upgrading to take advantage of redesigned procedures are outweighed by the benefits.

- The ultimate benefits of digital avionics will be realized in a network for automatic information exchange, but no platform yet exists.

- En-route control centers are not universally equipped to accommodate hi-tech operators by providing more efficient routing directions.

- The NAS does not respond quickly to improvements in weather conditions, perpetuating weather-related congestion and delays.

- Mandatory retirement regulations are removing a critical number of controllers from the NAS in the immediate future.

This paper further discusses these major difficulties of advancement, as well as developing solutions and recommending policy changes and actions. It is a critical time for the future livelihood of the NAS; with appropriate planning, this nation can redesign its air transportation system and remain a world leader in the field.

1 INFRASTRUCTURE TRANSFORMATION

The hub-and-spoke system first envisioned by Robert Crandall, former head of American Airlines[1], currently dominates the commercial airline setup in the NAS. According to the National Business Aviation Association (NBAA), "Approximately 70 percent of all airline passengers travel to or from the top 30 air carrier hubs."[2] These hubs have become increasingly crowded, however, and are faced with delays and possibly even gridlock. Commercial airline traffic is the largest contributor to congestion of runways and airspace around runways at these hubs, consisting of almost 60 percent of their total airline operations.[3] At O'Hare airport, for example, the airport's operations have become so overcrowded that Secretary of Transportation Norman Mineta threatened to intervene if the commercial airlines do not take steps to reduce congestion caused by high frequency flight schedules.[4]

1.1 Moving Away From Hub Airports

Despite the added stress on the major hub airports, there are still underused runways and airports across the United States. Shifting traffic to non-hub airports would alleviate the stress on hub airports and better utilize NAS resources. In an FAA study, Sacramento Metropolitan Airport (SMF) hypothetically took 200 diverted operations from the San Francisco International (SFO) hub. Under Instrument Meteorological Conditions (IMC), the distribution of operations reduced delays at SFO by 70 percent using forecasted 1998 data.[5] Utilizing non-hub airports such as this one would reduce the traffic at the major hub airports. Although there were benefits of the hub-and-spoke system when it was in implementation, alternative systems would better serve the NAS stakeholders as well as the nation.

1.2 Regional Airports

Increasing the use of smaller regional airports according to a point-to-point system would dramatically lessen the congestion in US airports and airspace. These smaller airports could service smaller airplanes and operate on a point-to-point basis, as opposed to the hub-and-spoke system, which would support the large, high passenger-density planes. An increase in the usage of point-to-point aircraft would reduce the amount of hub activity. Less frequent flights of the big jets at hub airports and more frequent flights of the regional jets between regional airports would create a less congested system overall, due to the distribution of hub traffic. Furthermore, if there are only a few flights connecting two major hubs such as Newark and Atlanta each day, then the small flights connecting to the smaller airfields from those hubs will be less frequent. General Aviation airports already exist in convenient locations to many travelers. According to John W. Olcott, President of the General Aero Company and former President of the National Business Aviation Association, 90 percent of the general population lives near a general aviation airport.[6] If these

[1] Hilkevitch, John, John Schmeltzer and Alex Rodriguez. "Hope Isn't Even on the Radar." Chicago Tribune. 21 Nov. 2000.

[2] National Business Aviation Association, Inc. NBAA Business Aviation Fact Book 2004. p27.

[3] National Business Aviation Association, Inc. NBAA Business Aviation Fact Book 2004. p28.

[4] The Associated Press. "American, United OK O'Hare Flight Caps." Seattle Post-Intelligencer. 17 August 2004. < http://seattlepi.nwsource.com/business/apbiz_story.asp?category=1310&slug=Airline%20Delays%20O'Hare>.

[5] "1991-92 Aviation System Capacity Plan." Department of Transit. DOT/FAA/ASC-91-1. 1991-1992. p5-2.

[6] Olcott, John W. General Aero Company. Personal Interview. 3 Aug. 2004.

GA airports also offered commercial airline service, travelers would have a shorter, more convenient commute to an airport. In order to increase usage on regional airports, economic incentives could be implemented. If the most congested airports in the nation charge market-based usage fees (which are discussed in Section 2), smaller, regional airports will become a more popular alternative for commercial airliners.

Local landowners frequently oppose commercial aviation at GA airports. These groups fear a rise in noise pollution stemming from increased jet traffic. To address the landowners' concern, the local government could follow Chicago's lead. In order to reduce noise complaints in the areas surrounding O'Hare, the city "spent more than $130 million insulating over 3,900 homes and over $190 million on schools."[7] Although this investment has no chance of realistically solving the problem on its own, it can be one of many accommodations to local landowners. Other useful agreements could include limited operational hours and restrictions on overly noisy aircraft. Increasing activity at airports is a difficult task.

Frequency also becomes less of an issue for point-to-point travel due to fewer connecting flights. More connections lead either to more frequency or more time spent in an intermediate place that is not significant to a traveler's final destination. A decrease in the number of connecting flights also makes the system less vulnerable to propagating delays.

This discussion of point-to-point travel with smaller aircraft relates to NASA's Small Aircraft Transportation System (SATS)[8] program. Further research into the effects on congestion caused by a potential SATS program should be undertaken. Although the system will probably better distribute runway activity among underutilized airports, en route and TRACON air traffic control will become much more complex and crowded.

1.3 Ground Transportation Options

In line with the strategy for increasing usage of regional airports, the airports and local government should encourage improvements in supporting ground transportation. Specific transportation problems in the United States should not always be viewed in their respective subcategory of transportation. Sometimes, government officials should analyze the entire transportation system as a whole while searching for possible solutions or improvements. Ground transportation, for instance, can help reduce congestion in air transportation. Busses, rental cars, and rail systems would be advantageous methods of transporting people between regional airports and hub airports. Both EWR and JFK in the New York City area already have a rail link connecting the two major hub airports. Travelers may use the rail link to arrive at one airport and catch a connecting flight at the other, though this option is rarely practiced today. In order for consumers to exercise this option, user comfort must increase. As users become comfortable with these types of connections, consumers will use them more often. Emphasizing alternatives to air transportation would require governments to find a method of easing the use of ground connections between airports. A study of potential feasibility should be made, initially concentrating on the northeast United States.

Local authorities should allow airports to undertake construction projects in order to build off-airport infrastructure such as rail links similar to EWR and JFK so that a connected system may be realized. Or, other forms of cost-effective ground transportation (taxis, busses, rental cars, etc.)

[7]Daley, Richard M. U.S. Senate Committee on Commerce, Science, and Transportation Hearing on Modernizing O'Hare International Airport and Expanding Airport Capacity in the Chicago, Illinois Area. 21 March 2002. <http://commerce.senate.gov/hearings/032102daley.pdf>.

[8]For further information, see <sats.nasa.gov>

that connect airports should be made more available. In order to better serve their customers, airlines could subcontract these services to local ground transportation companies. Of course, city planners must also take into account the convenience of the traveler. For instance, most consumers do not like handling luggage in between transfers. Research into increasing ground transportation should be undertaken.

The European community has had considerable success with rail transportation. Possibly the growing popularity and decrease of technological barriers to maglev trains will allow the United States to create a comparative rail transportation system. Since this new wave of rail transportation will be designed to support passengers instead of freight, a maglev system may have more success in the passenger rail service business. The government should invest in research of maglev feasibility.

1.4 Consumer Awareness of Multimodal Travel Options

Increasing consumer awareness of travel choices will more efficiently distribute passengers across other transportation modes. With the advent of the Internet, several online companies have emerged that allow consumers to search for and easily find information comparing the services of competing airlines. The most notable companies are Expedia, Travelocity, and Orbitz. Although information such as number of stops and chance of delay are listed for comparison on these websites, most consumers attempt to find the cheapest itinerary in order to travel from origination to destination. Besides offering information on car rentals in specific areas, these online companies only allow consumers to compare airline tickets sold by the major legacy carriers. They do not take into account other modes of transportation.

Despite the limited availability of non-commercial and unbiased information, these online websites offer better alternatives, whether through cheaper rates or ease of use. Many people are moving away from direct airline ticket sales and travel agent deals and moving toward online ticket purchasing through these websites. If the website services went one step further and offered comparative information that included alternatives to the legacy airlines, consumers could realize the potential of alternate forms of transportation. Not only will consumers save money, but other modes of transportation will also be encouraged. If these websites were not feasible private companies, the government could implement a program to educate the consumer, comparing prices and travel times of different transportation options.

Websites or a non-traditional travel agency could also administer an on-demand system for the traveling public. Instead of matching customers with the preexisting flights of the airlines, these on-demand agencies could create flights (or other modes of transportation) for their clients by grouping together travelers with similar itineraries and time frames. Once groups are formed, the agency could contact various transportation providers and charter a flight, bus, etc. for their clientele. The agency would charter the transportation providers that offered the best services, based on their clients' priorities (time, price, comfort, etc.). On-demand flights would not be limited to the current list of commercial airports; they could expand and utilize GA airports too, under the aegis of business aviation. An advanced, comprehensive on-demand system would develop an efficient national or worldwide transportation system that minimizes the waste of excess flights or fuel. Researchers should conduct studies on the feasibility of an on-demand system, initially concentrating in the populated northeastern United States.

Some may argue that alternative forms of transportation cannot keep up with the speed of air travel. Although it is true that air transportation is the fastest form of travel while en route, the increase in airport security lines as well as the commute time between airports increases the total time spent traveling and is generally equivalent to the time it takes to travel by ground transportation. From door to door, an average commute with most of the distance covered through an airline averages a traveling speed of 90 miles per hour.[9] Although jet transports travel at transonic speeds, they are only slightly more efficient than traveling by automobile for short routes. Furthermore, ground transportation is less affected by changes in weather, a factor that plagues air travel. Of course, air travel will always be more efficient when traveling from coast to coast or from country to country. An emphasis on alternative forms of transportation on smaller commutes, however, will vastly increase the capacity of the NAS. In a Congressional hearing, it was reported that "The American Helicopter Society has developed data-based on research performed by NASA Ames Research Center indicating that flights under 300 miles account for 40 percent of arrivals and departures at the top 63 hub airports in the country."[10]

These shorter commutes are the flights most likely to be replaced by other forms of transportation. Reducing or eliminating 40 percent of flights at the most congested airports in the country could do wonders for the congestion level of the NAS, and would not add significant time to most people's commutes. The Department of Transportation should undertake a study on the effect of increases in alternate forms of transportation in between adjacent city centers, specifically with increased ground vehicle usage.

1.5 Airport Infrastructure

The most apparent method of increasing capacity is to expand airport infrastructure. Judging by the goals of the Operational Evolution Plan (OEP), the FAA already believes in the potential for new runways. In the OEP, 50 to 55 percent of the planned capacity increase stems from construction of 15 new runways at some of the most congested airports in the country.[11] The long-term effects of these investments in airport infrastructure are optimistically noted. A recent study completed by DRI-WEFA, Inc. suggests that for every dollar invested in airport infrastructure today, there will be a five-dollar return on the investment in the future (from delay reduction through 2020).[12] Not surprisingly, this study also recommends that policy-makers finish all current and planned runway projects.

Despite the forecasted future gain, simply planning to build more runways is not necessarily a comprehensive answer to all the congestion problems in the NAS. It is an extremely difficult process. Investments in new runways are costly in the short term and also involve a considerable time investment. Runways can take 10 to 14 years to implement, and the current FAA Operational Evolution Program has had some difficulties in the building process. Considering the 15 runways it initially planned to construct, only one project has had initial success. Six others are experiencing delays, and one has been cancelled.[13]

Obviously, adding runway capacity is not always the easiest solution. Sometimes adequate space is not available. In addition, runway capacity increase without the corresponding excess capacity in nearby terminal airspace will not increase throughput. The ability of air traffic controllers to safely track aircraft has its limits, too. Even if an airport succeeds in adding infrastructure, an

[9] Olcott, John W. General Aero Company. Personal Interview. 3 Aug. 2004.

[10] United States. Cong. House. Subcommittee on Space and Aeronautics. A Review of Vertical Takeoff and Landing Technology in the National Airspace System. Hearing, 9 May 2001. 107th Cong., 1st sess. 2001.

[11] "National Airspace System: Long-Term Capacity Planning Needed Despite Recent Reduction in Flight Delays." General Accounting Office. GAO-02-185. Washington, D.C.: 14 December 2001.

[12] The National Economic Impact of Civil Aviation. DRI-WEFA, Inc. July 2002. p4.

[13] "National Airspace System: Reauthorizing FAA Provides Opportunities and Options to Address Challenges." General Accounting Office. GAO-03-473T. Washington, D.C.: 12 February 2003. p16.

increase of capacity may encourage airlines to schedule more flights and quickly consume the additional capacity. Capacity expansion is only as effective as the efficient use of that capacity. There exists a number of inefficiencies in the system (described in the rest of the report), and if these are not dealt with, any additional capacity will be consumed by surplus demand with only slight improvement in on-time performance/congestion reduction. Improving the process of adding new runways to existing airports is a key undertaking for NAS capacity improvements. Comparing the process for infrastructure improvements at ORD over the last couple of years would be a beneficial study to learn more about infrastructure updates at crowded airports in the United States.

1.6 Business Jets

In order to reduce the amount of business travel demand on commercial airliners, businesses should better utilize private business jets. Business jets offer an alternative mode of air transportation and have the ability to access a wide variety of GA airports. Ideally, the business jets would concentrate themselves in areas of the NAS that are underutilized, with more point-to-point travel as well as smaller airport usage. According to the NBAA, almost 5,300 airports service general aviation aircraft (which includes business aviation), compared to only 558 airports that service traditional air carriers.[14] Granted, most major businesses are located near major cities, which in turn have major airports. Most major cities, however, have smaller, less known airports that mainly (or exclusively) service general aviation. Three major airports service New York City (JFK, LGA, and EWR), for example, but other smaller airports are also available, including Teterboro, Islip, Morristown Municipal Airport, and the Downtown Manhattan Heliport. Although businesses that are likely to own business jets are located near major airports, these businesses are also likely to be in the vicinity of smaller, less congested airports. Utilization of other airports would better distribute traffic throughout the NAS, both on the ground and in the airspace around major city centers. Increasing the popularity of business jets, even for non-business travel, would shift the traffic concentration of the NAS and more equally distribute airport usage. Business jets also offer an on-demand alternative, which is discussed in Section 1.3.

1.7 Helicopters, Tilt-rotors, and Other Strange Birds

Using Vertical/Short Takeoff and Landing (V/STOL) aircraft can decrease the stress of traffic on runways. STOL aircraft do not have the same runway length requirements as the conventional aircraft used by the airlines or many general aviation participants. Therefore, runways for STOL aircraft can be built that require less space and pavement (although still a difficult undertaking, as discussed above), or existing runways could possibly be partitioned to allow multiple landing and takeoff operations at once. Researchers should conduct a study on the feasibility of simultaneous runway operations on the same runway and its potential effect on the NAS. Additional research could include redesigning commercial jet transports to incorporate STOL features.

If utilization of STOL aircraft proves potential successful, infrastructure changes at the nation's airports need to commence. The FAA would have to foster research and development in the flight technologies and develop standard procedures for STOL operation in the NAS. Furthermore, updating taxiway infrastructure at airports to accommodate the setup for simultaneous landings or takeoffs on one runway will be necessary for maximization of STOL benefits.

[14]National Business Aviation Association, Inc. NBAA Business Aviation Fact Book 2004. p27.

Vertical Takeoff and Landing (VTOL) aircraft, which include helicopters as well as tilt-rotors, can further reduce the congestion on runways since they do not require conventional runways for normal operation. According to data from the American Helicopter Society presented during a hearing before the Subcommittee on Space and Aeronautics in the House of Representatives, ”Replacing half of these flights [which are under 300 miles and operate at the nation’s hub airports] with VTOL aircraft (having 20 seats or more) using simultaneous noninterfering [sic] (SNI) approaches, system capacity in the NAS would be increased by 30 percent.”[15] VTOLs can help reduce congestion by tapping less used airspace in the NAS that is already nearby current airports. Airports can accomplish this feat by taking advantage of VTOL ports. Locating these VTOL ports at a convenient yet safe distance from airports will allow an airport’s capacity to significantly increase. In addition, connecting the VTOL ports with the traditional airport facilities by means of a train, bus, or other mass ground transportation system would allow connecting flights to exist between the two modes of air transportation, thus allowing capacity to increase even within a hub-and-spoke system. With this setup, VTOL aircraft can also decrease the stress on airspace around runways, because a significant number of the flights will be routed to a VTOL port outside of the standard runway flight paths.

VTOLs have been around for decades in the form of helicopters. For various reasons, however, they have not become a viable commercial transportation option. One of the major difficulties with helicopters is the noise. A jet-powered VTOL would counter this problem and possibly add a viable commercial transportation alternative. This type of technology, however, will not be viable on a large scale for decades. If VTOLs do eventually become potentially successful options, the FAA must recognize the differences between VTOLs and conventional aircraft and allow VTOLs to utilize their different flight characteristics to their full advantage. Currently, the FAA treats VTOL like fixed-wing aircraft, thus voiding all benefits VTOL craft can offer to the NAS. For instance, the FAA requires VTOL to queue and follow the same approaches as other conventional aircraft approaching runways for landing. Since the VTOL generally travel slower than fixed-wing planes, VTOL craft require more spacing. Furthermore, the approach trajectory that the VTOL must follow burns more fuel and cuts back on the fuel efficiency of the vehicle, thus making a seemingly viable option to fixed-wing travel less attractive. Having separate management policies for different types of aircraft will allow more aircraft to land, since the various management policies could be specifically tailored to each type of craft instead of having each craft fit under one broad, inefficient aircraft approach management policy.

1.8 Seaplanes and Other Novel Aircraft: A Forgotten Resource

Incorporating seaplanes and other aircraft, which use less of the existing air transportation infrastructure by employing open waterways instead of runways, would further relieve the current burden on the NAS. These alternative aircraft may be marketable niches that entrepreneurs can pursue, such as a seaplane transportation system. Many of today’s most populated cities were established near bodies of water to facilitate early commerce. Seaplanes could readily connect major metropolitan areas on the east and west coasts, as well as many interior locales. Although seaplanes are heavier and therefore require more fuel, this cost could be offset by the reduction in airport traffic as well as the lack of comparable landing fees on bodies of water. A cost-benefit analysis of a seaplane transportation system should be undertaken to evaluate this alternative. Several potential issues with seaplanes must be analyzed, such as public acceptance, noise prob-

[15] United States. Cong. House. Subcommittee on Space and Aeronautics. A Review of Vertical Takeoff and Landing Technology in the National Airspace System. Hearing, 9 May 2001. 107th Cong., 1st sess. 2001.

lems, space for loading and unloading docks near major metropolitan centers, and the effect of weather delays on a seaplane transportation system.

The government can help expedite the creation of a seaplane alternative in the NAS. Funding research and development into large, passenger-oriented seaplanes should continue. The Beriev Aircraft Company already produces a large-scale passenger seaplane that utilizes a jet engine instead of a consumer-despised propeller. Improving on this technology would allow for more fuel efficient operation, making seaplanes even more attractive.

Local governments should also allow and encourage commercial seaplane operation on local waterways. Seaplanes do not pose a major threat to environment concerns, nor do they often interfere with boat traffic. A commercial seaplane industry would actually help a local area, adding to the economy. With governmental cooperation and the entrepreneurial instinct of businesspeople, a commercial seaplane industry could serve the nation's transportation needs.

2 PRICING STRATEGIES FOR EFFICIENT CAPACITY ALLOCATION

Tonight's television news broadcasts images of planes queued at O'Hare International Airport and voices of miserable would-be passengers waiting for their flight, now hours delayed, to take them home. One such man wonders whom to blame the airline, the airport, or the air traffic controllers? as he clutches his $79 ticket to New York. Talking heads inform viewers that there is a "capacity shortage" at the airport. Viewers wonder what ought to be done to alleviate the 'shortage' build another runway? Another airport?

What observers of airport gridlock ought to first ask is: why, fundamentally, does this shortage exist? Surely, there are many scarce resources for example, bandwidth for radio stations and cellular phones. Yet consumers are satisfied (economically speaking) with the quantities of these goods as allocated by the government. Demand for American airspace, however, exceeds the available supply at all three levels of control airport, TRACON, and en route at selected times and locations. Why?

Unlike bandwidth, which is auctioned to the highest bidder, ATC is provided to operators for a price entirely unrelated to its market value. We refer to "market pricing" as the mechanism (i.e., a free market) by which the price of a good corresponds to the amount consumers are willing to pay for it. Generally speaking, market pricing serves three important purposes: First, it allocates particular goods to the consumers who attribute the highest value for them. Second, market pricing indicates opportunity cost (i.e., the value of alternative uses of the resources used in production). Lastly, market pricing provides a signal as to whether more or less quantity of resources should be devoted to the production of the good.

To operators, use of the National Airspace System (NAS) is a scarce resource. Because the quantity of NAS is limited by physical constraints (capacity, environmental constraints, etc.), its long-run aggregate supply does not vary with the marginal cost of production, unlike a normal good whose long-run aggregate supply depends on quantities of inputs traditionally formulated as land, labor, and capital. The price of a scarce resource is determined entirely by the value that consumers place upon it. A market for a scarce resource serves the same purposes of allocative efficiency and reflecting opportunity cost, but instead of signaling investment/divestment, prices signal the need to invest in alternative resources (e.g., railways) and research and development (e.g., augmented GPS navigation) in order to relax physical constraints. Other scarce resources are not in shortage because a market exists for them, ensuring that the goods are priced at market value.

The nightmarish specter of jets queued for hours at O'Hare is typical of the chaos one sees when more consumers want to purchase a good than could afford it were it priced at market value. When price ceilings are imposed at levels below market value, quantity demanded exceeds quantity supplied, resulting in shortages. Correcting an economic shortage is a matter of freeing the price to reflect the market value of the good by eliminating price ceilings.[16] Of course, it is also desirable to alleviate inherent capacity limitations to increase long-run aggregate supply, but this line of attack requires much more time to research, develop, and implement and is therefore an emphatically long-term, technical solution. Both market-based and technological reforms will reduce congestion, but this chapter deals only with the former.

President Reagan's maxim is largely applicable to the National Airspace System: in many

[16] We are grateful to Steve Welman of MITRE Corp. for introducing us to the idea of market-based approaches to NAS congestion.

ways, government is not the solution to the problem; government is the problem. Federal, state, and local regulations have created a pricing structure geared toward allocative inefficiency, unclear opportunity costs and minimal signaling capability.

The following solutions attempt to create a market for the use of the National Airspace System. We focus on the pricing structure of two resources consumed by aircraft operators: Air Traffic Control (ATC) and the airspace/groundspace controlled by the airport. We demonstrate the current inefficiencies in each pricing system and explore possible routes of reform. We then address potential concerns, particularly those relating to natural monopolies.

2.1 A Fairer Federal Ticket Tax

Airlines, cargo carriers, and other commercial operators consume ATC as a resource, as an input of the production of their service passenger or cargo transportation. One way in which the federal government has misaligned its usage fees with the market value of national airspace usage is the structure of the federal taxes which fund FAA operations:

Currently, federal ticket tax consists of a 7.5 percent tax on the passenger's base fare, a small flat fee per passenger per segment of flight[17], and a per-passenger security tax.[18] These taxes cover most of the FAA's operational budget; for example, this revenue covered 92 percent of the agency's 2002 budget.[19] With the exception of the security tax for baggage and passenger screening, these per-passenger taxes do not reflect the value of air traffic control (ATC), usage which is valued on a per-flight (i.e., one takeoff, one landing, and the period in between) basis and not a per-passenger basis. This misaligned price structure leads to a number of inefficiencies. For example:

- The air traffic controllers paid by the ticket tax must give an aircraft the same level of attention whether it is a B747 carrying 400 taxpayers or a CRJ200 carrying 40.[20] Despite the identical governmental resources required per operation, the revenue generated for the government by the above operations varies greatly.
- Likewise, the value of the ATC consumed by the airline is the same for any given flight regardless of load factor (i.e., percentage of seats occupied by passengers). However, the payments received by ATC varies directly with load factor.
- Furthermore, ATC provides the same service regardless of whether a flight is operated by a low-fare airline or a legacy carrier. However, the income ATC receives for the operation could vary greatly between the two. In fact, routes on which there are multiple competing carriers may tend to be more congested and more competitively priced, so there may be incentives toward an inverse relationship between per-plane ATC resources consumed and per-plane ATC revenue.
- ATC is priced identically for on-peak and off-peak service, though operators value ATC differently at different times of day.[21]

[17] Federal segment tax is currently $3.10 per segment per passenger.

[18] In addition to federal taxes, the passenger often pays his airport a Passenger Facility Charge (at most $4.50) for airport improvement.

[19] "Aviation Taxes and Fees." General Accounting Office. GAO 04-406R. Washington, D.C.: 12 March 2004.

[20] ATC divides aircraft into Light, Medium, and Heavy. The three are not interchangeable, but one is not necessarily worse for ATC to work with; for example, a Light cannot follow closely in a Heavy's wake, but then it could be followed by another Light, so the overall effect of larger planes being able to follow more closely but requiring more separation behind tends to cancel itself out.

[21] Peak periods tend to occur at the beginnings and ends of workdays, sometimes with a miniature "lunch crunch"

- ATC is priced identically for service at all airports, though operators value ATC differently at different airports.
- Connecting flights on the same ticket are treated as one flight by the current tax structure (with the exception of the segment tax). However, these series of connecting flights constitute twice as much or more work (i.e., two or more takeoffs, landings, etc.) for ATC.

Thus, the market for ATC is distorted over several dimensions.[22] Additionally, there is one potential inefficiency fostered by the current practice of applying the ATC tax to passengers:

- Airlines, not passengers, are the consumers of airspace, but the passengers are being taxed for its consumption. Under the current practice of passenger taxation, passengers' demand functions would first shift in response to any tax reform, and airlines would alter prices in response to these behavior shifts, an indirect revenue-based adjustment that does not result in allocative efficiency.

Considering these inefficiencies, we might expect a more efficient ATC pricing system to have the following attributes:

- Operators (e.g., airlines) would be charged directly for ATC costs, and federal passenger taxes (excluding security tax) would be eliminated.[23] Such is NAVCANADA's method of billing ATC costs.[24]
- ATC price would be fare-invariant; low-fare and legacy carriers would be assessed the same ATC charge for otherwise similar flights.
- ATC price would be invariant over size of aircraft.
- ATC price would be invariant over load factor.
- ATC price would reflect the time-variant (i.e., on- vs. off-peak) value of ATC.
- ATC price would reflect the location-variant (i.e., which airports serviced) value of ATC.
- Connecting flights would be subject to tax equal to the sum of taxes upon each segment purchased and operated separately (with each segment being taxed according to its time-variant value of the segment's departure and arrival).

Cargo operators (e.g., UPS) currently pay no ticket tax but are instead subject to a 6.25% transportation tax. Airline and cargo operations operate along similar routes at similar altitudes, so one doubts that any discrepancy in ATC pricing between commercial and cargo carriers is appropriate. Cargo carriers do tend to operate more during less-congested periods (e.g., late night and early morning), but a time-variant ATC pricing system would account for off-peak usage. Because

in between, and during major holiday travel (e.g., the days surrounding Thanksgiving).

[22]These "dimensions" are not entirely independent of one another; for example, low-fare carriers tend to fly only one or two types of aircraft and have low percentages of connecting flights, whereas legacy carriers tend towards higher fares, more diverse fleets, and high percentages of connecting flights, etc.

[23]Of course, airlines might still try to bill the cost of ATC separately from the fare just as some airlines absurdly demarcate a "fuel surcharge" on tickets, but the airlines would still be responding to cost changes (instead of inefficiently responding to passenger demand shifts).

[24]NAV CANADA prices ATC quite oddly, with price directly proportional the product of the great-circle distance between origin and destination and the square root of the maximum takeoff weight of the aircraft. Emphatically, we are not endorsing NAV CANADA's pricing scheme, only its practice of billing operators directly.

the current transportation tax is subject to many of the same inefficiencies as the ticket tax, we recommend its elimination as well. Both ticket tax and transportation tax should be replaced by the same revised tax structure.

What are the inputs to calculating a revised ATC operations tax, assessed per commercial operation? Origin and destination airports and departure and arrival times are factors we have suggested should be incorporated into the structure. Given these inputs, we can obtain historical volume and delay information from the DOT's Bureau of Transportation Statistics, to which the largest 18 domestic carriers (see Appendix A) are required to file information on delays and cancellations. The Bureau of Transportation Statistics collects, analyzes, and presents data useful in analysis of air traffic from 1995 to the present. One category of delay is "NAS delays," preliminary delays imposed by ATC (often by the FAA control center) to prevent gridlock. Using this category, delays which affect ten percent of all flights and constitute about one third of total delays,[25] we can estimate rates of NAS delay per airport; take the total of NAS-delayed arrivals or departures by all reporting airlines servicing the airport, divided by total reported operations.[26] This NAS delay rate is a simple, albeit crude, indicator of congestion. It should be calculated separately for peak and off-peak periods. Not only can we can determine relative rates of NAS delays per airport, we can determine rates per route (i.e., per origin-destination pair). Some statistical measure of route demand, perhaps the covariance of delay rates at origin and destination, may prove useful if a more sophisticated pricing scheme is desired.

The current flat rate does have one seeming advantage: simplicity. However, technological advances permit us to incorporate a tax table into the ATC tax system with relative ease: An operator's identification, origin, time of departure, etc. is contained in a flight strip, passed along from controller to controller, origin to destination. Upon landing, an operation's flight strip (which includes operator identification and time and location of departure) could be updated with time of landing and put in a "tax box" instead of simply being discarded. Tax would then be assessed to the operator and paid on the same schedule as the current ticket or transportation tax it replaces.

GA non-commercial operators pay neither ticket nor transportation tax. However, GA non-commercial operators do pay a fuel tax from which commercial operators are largely shielded.[27] Because non-commercial GA operators tend not to operate turbojet aircraft, they tend not to consume the same airspace as airline and cargo operations.[28] GA non-commercial operators also are less likely to utilize congested approaches to the 31 major airports, especially if the landing fee deregulations (see next chapter) are adopted. GA non-commercial operators also tend to fly under Visual Meteorological Conditions (VMC) and thus to consume less ATC resources. Because GA non-commercial operators generally do not consume highly valued ATC resources and do pay a fuel tax from which commercial operators are largely shielded, we do not recommend subjecting GA non-commercial operators to the ATC tax table. However, in the future, as "personal" very light jets (VLJs) become increasingly abundant, it may make sense to charge them for certain flight

[25] US DOT Office of Aviation Enforcement and Proceedings. "Air Travel Consumer Report." August 2004.

[26] Although reporting airlines are required only to report performance at the top 31 airports, all reporting airlines voluntarily provide delay information for their entire systems.

[27] Federal fuel taxes are 21.9 and 19.4 cents per gallon on jet fuel and aviation gasoline, respectively. Commercial operators may claim a tax refund of 17.5 and 15 cents per gallon, respectively. Note that all 50 states impose some form of aviation tax, often including a fuel tax among other fees such as registration fees, property tax, etc. Source: National Business Aviation Association (NBAA) Business Aviation Factbook 2004.

[28] According to the FAA, estimated 2003 active GA hours flown included 2.7 million for turbojet operations, compared to 21.8 million for piston-engine, turboprop, and rotorcraft airframes. Note that this figure includes commercial air taxi service which may account for many of the turbojet operations. Personal use and flight instruction account for over half of GA hours flown. Source: NBAA Factbook.

profiles that utilize airspace already in high demand.

Given the above restructuring, the federal segment tax (currently $3.10 for all commercial segments into non-rural airports) should be eliminated, as it is a strictly per-passenger tax and suffers from the above size- and load-factor-variance and time invariance. Its efficient dimensions, invariance over fare and status as connecting flight, are already included in the above reform.

Currently, domestic US flights passing over Canada are subject to NAV CANADA's ATC fees, fees which may distort the incentive structure we are trying to promote. Therefore, we propose that American first-freedom flights over Canada receive an ATC discount equal and opposite to the cost assessed by NAV CANADA in cases of flights where US ATC component price exceeds Canadian component price.[29] This discount would help maintain the allocative efficiency of the proposed system. In the short run, until airspace consumers adjust to the changing prices and before additional economic reforms (see below) are implemented, the overall effect of the tax restructuring will likely be an increase in tax revenue. While in theory the change in tax structure could be revenue-neutral, any meaningful reduction in delay cost to operators must be converted into a corresponding increase in explicit cost of operation. It is unlikely that consolidation toward larger planes and more efficient operations will mitigate this increase in tax revenue in the short run, since the changes we seek to incentivize involve strategic reassessment of business models and (in many cases) shifts in types of aircraft operated. This short-term increase in revenue should be designated for increasing capacity (via the Airport Improvement Program) and improving ATC technology, particularly those recommendations in this paper requiring additional sources of funding.

While restructuring the federal ticket tax will not solve all the NAS's problems, the measure is at least feasible under federal jurisdiction. More dramatic changes are needed, but addressing further disincentives to efficiency at the various state, local, and municipal levels of airport regulation is a more daunting task, one which raises questions of jurisdiction.

2.2 De-Regulation of Landing Fees

Another important input to airline operations is airport usage. At all but three airports (JFK, LGA, and DCA), the monetary costs of domestic landings are simple per-weight landing fees, limited (along with per-square-foot rental fees for gates and other facilities) by local legislation or legislatively appointed bodies to an amount recovering the costs of airport operation.[30] This per-pound landing fee is based largely on antiquated assumptions about how landings impact a runway's durability, though building infrastructure large enough to accommodate these large jets does, of course, require more capital investment. (Any aircraft paying the landing fee is entitled to land, versus the slot-controlled system which permits only those operators assigned quota in advance to land at the three above airports under normal circumstances.) Let's motivate an examination of the discrepancies between cost to operators and value of airport operation with a brief thought experiment:

- O'Hare airport charges a landing fee of $2.61 per 1000 pounds.[31] A CRJ200 weighs around

[29] The "first freedom" refers to the right to fly over a country without landing. It is recognized through the International Air Services Transit Agreement (which Russia, China, and some other nations do not recognize). It does not prevent sovereign countries such as Canada for charging for en route control, even though similar control is provided free of cost by the United States to first-freedom Canadian flights over America.

[30] We use the term "landing fees" throughout, but the airframe's certified Maximum Take-Off Weight (MTOW) is more commonly used than landing weight.

[31] Domestic or international. To those "non-signatories" who don't rent gates, the landing fee increases to $3.26 per 1000 pounds. International operators must also pay a per-passenger embarkation/disembarkation fee.

50,000 pounds (with fuel) and carries up to 50 passengers. A B747-400 weighs around 850,000 pounds (with fuel) and seats around 500.[32]

- By FAA standards, both planes require the same 6,000-foot separation on takeoff and 3-mile separation in the terminal area (whether these uniform separations are appropriate is not addressed here). Both require the same clearance procedures and the same amount of controllers' time. Both require one gate to unload and load passengers. Distress to the runway is not dramatically increased by the larger jet.
- However, the 747 costs $1836, whereas the CRJ200 costs $108, to land as a domestic signatory at O'Hare. Amazingly, it even costs more per passenger ($3.67 vs. $2.16) to land our hypothetical 747.

Confronted with the above scenario, we intuitively sense two problems:

- The resource, i.e., runway usage, consumed by the operator is valued on a per-plane basis. Consumption of this resource is essentially invariant over the size and load factor of the plane. However, the resource is priced according to weight. Thus, the current landing fee system is inefficient in structure.
- A few dollars per passenger is the only explicit marginal cost to the airline of landing at the country's most popular airport; a flight landing in the middle of nowhere would incur all the same costs (in the tens or hundreds of thousands of dollars) except for the small landing fee.[33] We sense that the value of landing at O'Hare is much greater than the cost of the landing fee. Thus, the current landing fee system is inefficient in scale. Thinking back to the previous section, we anticipate a third problem:
- Travelers to or through Chicago probably have a preference for certain arrival times. However, the landing fee does not vary with time. This time-invariance is another structural inefficiency.

Although the outcome of this thought experiment is striking, the strange realities of airport regulation are even starker. Demand for airport operations exceeds supply whenever the operator's value of landing exceeds the price the large airport is allowed to charge, particularly during peak periods of demand. During these periods of increased demand at major landing fee- controlled airports, the number of planes desiring to land regularly exceeds the number the airport can safely allow to land. Under commonplace residual-basis pricing schemes, many airports must lower their landing fees in response to increased usage, which in turn increases the demand for using the airport even more.[34]

Because of the low price ceiling on landing fees, excess demand during peak periods creates congestion, resulting in considerable delay. This delay has enormous implicit costs: decreased airline income (for example, fewer people want to fly after experiencing delays, nor can they if their planes are stuck somewhere else) and increased airline expenses (for example, increased costs of fuel and labor incurred by mid-air holding patterns, ground delays, etc.). These large implicit costs of delay dwarf the explicit, limited price of the landing fee.

[32] The B747 seats 416 to 524 depending on configuration (i.e. whether a luxury class is incorporated).

[33] ORD ranks first in total airport operations. Source: FAA, 2004.

[34] These residual-basis funding agreements are sometimes known as "single-till," where non-aeronautical revenue is also included in calculating total revenue, which must be capped at cost-recovery. This cap determines landing fees. Elsewhere, a "double-till" agreement considers only aeronautical revenue when calculating cost-recovery-leveled price.

Current regulations of landing fee pricing result in an undesirable system where delay, not the landing fee, is the primary cost of airport operation. As one economist put it, ”The current system for allocating airport capacity to airlines at large, congested airports is a combination of delay imposed through queuing, ground stops, ground delay programs and miles in trail, combined with the vertical integration of airlines into the airport industry through exclusive and preferential gate use agreements. Landing fees play a relatively small role in the allocation of airport capacity.”

Delay is a far less preferable pricing mechanism than explicit monetary fees of airport operation because of consequent negative externalities. Much as pollution harms the polluter and the non- polluter alike, the negative externalities of delay punish efficient users of airspace as much as inefficient users; delays affect not only the flights to which a flight may subsequently connect and other departing flights ”down the network” but ”up the network” as well if, for example, an airport controller institutes ground holds at a congested airport or en route controllers close congested sectors. In the ”gridlock effect,” incrementally small amounts of congestion in the network reinforce one another and cause large delays. (The optimist's corollary is that likewise, small reductions in congestion can dramatically cut system-wide delays.) Because delay does not result in low revenue only for those who overload the airspace and cause delays, nor does it result in high revenue for those who promote airspace efficiency, delay is inefficient as a pricing mechanism and is less preferable than explicit monetary per-operator fees.

Because delays decrease airline revenue, airlines are willing to pay to reduce delays (so long as the increased revenue meets this marginal cost). Therefore, it does not make sense to keep landing fees fixed. Local regulators of primary airports need to free current pricing restrictions to allow the price of operations to reflect the market value of the resources which operators are consuming. The increased revenue from this fee deregulation would contribute directly toward capacity expansion and technological upgrades at the same airport, thus directly addressing the causes of congestion. In a Brookings Institute study, economists Stephen Morrison and Clifford Winston proposed a congestion pricing scheme and estimated that its implementation would yield annual net benefits to society of nearly $4 billion.[35]

Such a restructuring would require a fundamental shift in how landing fees are assessed towards a more realistic valuation of the resources an airport provides. To allow airports to alter landing fees from a strictly per-pound basis to a function with some flat, per-flight component (reflecting the one takeoff, one landing and so forth) would more accurately reflect the value of the major airport's resources.

Even more importantly, this per-plane value of airport use is dependent upon the time of operation, as certain periods are in much higher demand than others. As demand for runway usage is greater during peak periods, large congested airports should be allowed to charge higher landing fees during peak periods and lower fees during periods of relatively low demand. Legacy carriers already charge higher fares for these peak-period flights, since customers with low price-elasticity of demand want these rush-hour flights, so any airline's claim that increased landing fees cannot be absorbed or passed on to the customer is dubious. In order for airport operations fees to be able to meaningfully indicate the value consumed, fees must be rescaled as well as restructured. When confronted with the congestion caused by scheduling frequent flights with fewer passengers instead of less frequent, larger jets, airline representatives are quick to point out that consumers with low price-elasticity of demand (e.g., businessmen) will take the most conveniently scheduled flight. However, if low-price-elasticity consumers want more convenient scheduling, then their desires are reflected in a willingness to pay extra for it. Airline representatives fail to men-

[35]Morrison, Steven A. and Clifford Winston. The Economic Effects of Airline Deregulation. Washington: Brookings, 1986.

tion that the current airport fee structure itself incentivizes more frequent, smaller jets like our hypothetical CRJ200. (We see larger jets in major markets, of course, because other costs fuel, labor, etc. mitigate against this irrational incentive.)

We have established that allowing landing fees to vary as functions of planes landing and on-peak/off-peak demand would allow the fee to more closely reflect the market value of landing. However, unlike the purely federal task of restructuring the ticket tax, landing fees are generally within the jurisdiction of municipal governments.

Airports agree to restrictions imposed by the federal government in exchange for revenue from the Airport Improvement Program, funded by federal taxes on aviation operations and accounting for less than 15 percent of a major airport's capital expenditures (and a greater percentage for small airports). Major airports also enjoy federal subsidy via their tax-exempt status.

According to one expert in airspace economics: "The ultimate restriction on the variation of landing fees resides with the federal government it is the main political force in this area. It is currently unclear the extent to which the federal government would allow an airport to charge market-based access fees. After the experiences of MassPort [Massachusetts Port Authority] in Boston, the airport industry has been reluctant to absorb the legal costs of working through the courts. Instead, the industry is lobbying the DOT to clarify what is considered legal under current legislation." The Department of Transportation should adopt a position that recognizes the per-plane, time-variant nature of costs of airport use and the economic necessity of having access prices reflect these costs.

Because municipally governed airports enjoy certain federal subsidies, they are inclined to consider federal guidelines for changes in fee structure, particularly if these changes are demonstrably beneficial to the airports. Some municipalities may attempt to hold out against deregulation. Because delays at one airport can cause delays elsewhere in the network, it is necessary for all thirty-one major airports, serving some seventy percent of emplanements (see Appendix A) to adopt the proposed changes; otherwise, improvements in some locations will be negated by deficiencies in others. The above jurisdiction, along with the reluctant threat of slot control (below) should be wielded to ensure compliance. More likely, airport operators will realize that increased pricing freedom is to their benefit, and the allocation of their scarce resources to the highest valued use is also beneficial to the consumer. We are emphatically not recommending airport privatization (as in Australia's 50-year leases, with option to extend for 49 more) because in many cases, municipalities paid to construct gates, terminals, runways, and other infrastructure, and such expropriation would be outside the proper jurisdiction of the federal government. Indeed, it may be possible to effect landing fee deregulation via FAA executive order.

2.3 Slot Control Elimination

Only three American airports are slot-controlled by federal authority: LaGuardia, JFK, and Reagan National. Under the slot-controlled system, the number of scheduled landings and takeoffs per time period is limited to the maximum number theoretically supportable by the airport, although the actual permissible rates are controlled by factors including weather and runway configuration. Delays still result when the permissible landing/takeoff rates are less than optimal or when flight arrivals/departures deviate from the scheduled distribution into more congested groups.

The threat of slot control (imposed at the discretion of the Secretary of Transportation) has proven to be somewhat effective in persuading airlines to decrease frequency of flights during peak periods, as when Secretary of Transportation Mineta gained a small reduction in airline operations under pressure from legislators, including Senator Peter Fitzgerald (R-IL), who urged the re-imposition of slot controls at an increasingly congested O'Hare.[36] Slot control, however, brings inefficiencies of its own.

In 1968, the FAA established slot controls at La Guardia, Washington (now Reagan) National, JFK, and O'Hare. Since then, airport congestion has increased immensely, but slot controls have not been expanded to other airports only three airports are now subject to slot control (O'Hare being provisionally removed from slot control in 2002). Obviously, slot control as currently practiced is not an effective or desirable means of controlling congestion. While it is economically more efficient to have flexible landing fees rather than slot controls for various inherent reasons (for example, slots must be purchased months in advance and do not allow airlines to quickly respond to changes in customer demand), there are also several inefficiencies promoted by the current slot-control system. The system prevents entry of new competitors by allowing a dominant carrier to obtain slots with the intentions to not use (or to underutilize) the slots and to prevent new entrants from gaining access to the airports. It also makes it difficult for a single customer to purchase corresponding slots for takeoff and landing at two airports thus controlled (a difficulty known as "aggregation risk"). Furthermore, slot control allows airlines to capture monopoly profits. Not only is monopoly pricing detrimental to consumer income, the losses incurred to airport income limit the airport's ability to expand infrastructure. The authors of "Experimental Economics and the Problem of Allocating Airport Slots"[37] identify several more inefficiencies inherent in slot control. However, unlike the bizarre structures of ticket taxes and landing fees, slot control at least attempts to grapple with the economic reality of the planes- per-time constraint at the terminal area[38] and airport levels.

While it is preferable to both the airport and the operator to shun slot controls for more flexible fee structures, it may be necessary to reform current slot control procedures so that it becomes a more viable option for other highly congested airports, and the viability of this option will persuade local regulatory bodies to adopt free-market reforms for their airports in order to pre- empt expanded FAA control. Grether, Isaac, and Plott propose several reforms to slot allocation that make economic sense: a primary slot market as a sealed-bid, one-price auction with aftermarket for grouped transactions; the possibility of "negative bids" for off-peak service, penalties for non-use and monopolization of slots.[39]

Although slot control could be reformed, slot control is an inherently cumbersome system due to the aggregation risk inherent in attempting to purchase all the necessary slots for a given operation, possibly deflating prices. While allowing group transactions might reduce aggregate risk, it is not certain that these group transactions will result in individual allocations of highest value. Furthermore, the scheduled nature of slot control makes it difficult for entrants and existing operators to exploit changing economic conditions. Therefore, we recommend phasing out slot control and implementing a reformed version only as a last resort should direct federal intervention prove necessary.

[36]"Fitzgerald Says Delay Controls Are Needed Again at O'Hare." Senator Peter G. Fitzgerald. 29 July 2004. U.S. Senate. <http://biz.yahoo.com/prnews/040729/dcth082_1.html>.

[37]Grether, David M., R. Mark Isaac, and Charles R. Plott. "The Allocation of Scarce Resources: Experimental Economics and the Problem of Allocating Airport Slots." Underground Classics in Economics. Boulder: Westview Press, 1989.

[38]Here, "terminal area" means the three-dimensional volume of space wherein aircraft approach and depart an airport. This area is controlled at the TRACON (Terminal Radar Approach CONtrol) level. The term should not be confused with the "terminal" describing the group of gates at an airport devoted to a certain airline or type of air travel (e.g., international).

[39]The authors also make some recommendations (admittedly) motivated by considerations other than efficient allocation of capacity, such as restricted markets for small communities, considerations which entail value judgments.

2.4 Federal Regulatory Policy and Anti-Trust Concerns

Regulatory policy itself contributes to airspace congestion by preventing airlines from responding rapidly to changing economic conditions. On one hand, government policy perpetuates obsolete business models through loan guarantees. On the other, it prevents airlines from streamlining operations by inhibiting the formation of alliances, code-sharing agreements, and foreign partnerships. The net effect of these interventions is that more flights are operated by more airlines than economically justifiable on high-demand routes.

Passengers traveling between hubs controlled by different airlines have more operators to choose from than the spoke route serviced by one airline. Thus, although each legacy airline wants to maintain service to another airline's hub to protect the integrity of its network, there may not be enough demand to justify both airlines' scheduling flights. Since the competitive equilibrium requires both carriers to offer flights, one method of reducing operator expense and airspace consumption while maintaining the benefits to the passenger is for airlines to form code-sharing agreements on flights between their hubs. The code-sharing agreement allows the airline to sell flights operated by the other airline as part of its connection package. As long as airlines do not collude in setting fares, customers enjoy substantial savings on code-shared routes: "Code sharing also has the virtue, predicted by economic theory and validated by experience, of producing lower fares from origin to destination. That is because carriers that set fares independently for each segment have no incentive to factor into their calculations the potential gains to other airlines associated with feeding traffic into the others' systems. Studies by Brueckner and Whalen conclude that such 'pricing synergies' generated by existing airline alliances have produced 18 to 20 percent reductions in fares on interline routes."[40] Though the effects of code-sharing on traffic are less well known, code-sharing may also have the added benefit of reducing traffic on heavily traversed inter-hub routes, since airlines can compete without being forced to schedule separate, frequent flights in order to appeal to customers with low price-elasticity of demand.

Despite their potential benefits, airline attempts to form code-sharing agreements have been met with logically inconsistent restraints from the Department of Transportation. For example, the Department of Transportation imposed upon the Continental-Delta-Northwest alliance, among other restrictions of a structural nature, a quantitative restriction on code-shared flights. Economist Alfred Kahn notes: "Code-sharing, subject to anti-trust conditions, either is or is not compatible with healthy competition. If it potentially leads to more effective performance, the kind of limit imposed by the Department of Transportation seems inherently anticompetitive."[41] The DOT should lift numerical restrictions on code-shared flights and rely upon the Justice Department to enforce existing anti-trust regulations against price and output coordination.

Likewise, while the federal government impedes the transition toward more efficient uses of airspace, it also perpetuates the existence of operations the market no longer desires. In late March 2003, over one and a half years since the post-9/11 establishment of the Air Transportation Stabilization Board (ATSB), US Airways closed on a $1 billion loan, $900 million of which is guaranteed by the federal government. The ATSB's June 2004 decision to deny a guarantee of $1.8 billion for a $2 billion-loan to United Airlines hopefully marks the end of ATSB loan guarantees, applications for which were due in late June 2002. Any further loan guarantees issued by the federal government would not preserve competition but would instead serve to reward uncompetitive and outdated business models. Although labor laws are generally too complicated for the scope

[40] Kahn, Alfred E. Lessons From Deregulation. Washington, D.C.: AEIBrookings Joint Center for Regulatory Studies. 2004. p11.

[41] Kahn. p17.

of this paper, it is worth noting that legacy airlines have sought to restructure in order to adapt to changing economic conditions including recession, terrorist attacks, and the low-fare carrier challenge, but their attempts to streamline operations have met with regulatory resistance because of potential ensuing job losses. It is not obvious that an airline ought to reach the brink of bankruptcy before being allowed to restructure.

Domestic airlines are further isolated from potential competitors by restrictions on foreign ownership and foreign alliances. For example, foreign corporations are prohibited from owning more than 25 percent of any domestic operation. This restriction was created to protect domestic airlines and their labor interests. Far from protecting consumers from anticompetitive business practices, these regulations deny consumers the benefits of fifth-freedom competition - for example, British consumers enjoy Irish low-fare carrier RyanAir's ability to serve domestic U.K. routes.[42] Foreign ownership restrictions also prevent relief of the financial distress of domestic airlines. The US should unilaterally relax restrictions on foreign investment partway to 49% of ownership in the short term. Allowing foreign-owned operators to conduct domestic flights without allowing American carriers the same competitive abilities, however, would put US domestic carriers at a distinct disadvantage. In the long term, US trade representatives should pursue reciprocal agreements reducing or eliminating restrictions on foreign ownership, much as it pursued the now-ubiquitous "open skies" third- and fourth-freedom agreements in the 1980's and '90's.[43] By removing the restriction against US domestic operations from the network optimizations of foreign-operated flights, and vice versa, one more constraint upon airspace efficiency will be removed.

2.5 General Effects of Above Reforms

The above measures provide market-based incentives towards airspace efficiency in that they provide incentives to operate larger-capacity flights at lower frequencies. Although the proposed changes to landing fees occur at the airport level, the efficiencies they promote will relieve congestion at the TRACON and en route levels, as will the proposed changes to the ticket tax.

Shifting the structure of landing fees and ticket taxes toward a per-flight basis does, to some degree, connect the performance of TRACON- and airport- level control to revenue generated after all, a point-to-point flight contains one takeoff, one departure, one approach, and one landing. The shift also attempts to match the demand for TRACON- and airport-level control with supply. However, the per-flight basis does not reflect the amount of time the plane spends en route or whether the route it takes is in high or low demand. (The fuel tax, to a slight degree, does serve to connect ATC revenue to operator time spent en route.) Is there an easy way to match the price of en-route control to the limited supply on congested routes? The short answer seems to be "no."

How would we determine the value of airspace occupied during en route travel? There seems to be no easy answer. Point-to-point distance is a poor gauge of market value; there are many short routes (e.g., Washington, D.C. to New York) in high demand and many long routes in low demand. Furthermore, between the same two points (e.g., Miami and New York) there are routes

[42] The term "fifth freedom" refers to country A's airlines' ability to operate domestic flights within country B.

[43] The term "first freedom" refers to overflight rights given by a country to commercial operators of another country. "Second freedom" refers to landings for technical, non-commercial purposes, such as fueling or repairs. American first and second freedoms are recognized by all nations but a few (such as Cuba). Third and fourth freedoms ensure the right of an operator to fly between (from and to, respectively) his country of registry and another country. The fifth freedom grants an operator the right to operate between two foreign countries, but it and also "sixth freedom" is sometimes used to describe the right to operate between two points in the same foreign country, a right granted only in rare circumstances (one example being Irish carrier RyanAir operating inter-U.K. routes).

in higher demand (e.g., over land) and lower demand (e.g., over the Atlantic). Neither is length of time (i.e., duration of flight) a good indication of value of airspace consumed. Granted, the ATC costs of surveillance, communication, etc. are proportional to duration of flight, but we have established that market value, not input cost, determines the proper price of the ATC resource.

Unlike the FAA, NAV CANADA (Canada's private ATC company established in 1996) explicitly charges operators for en route control, but it must resort to dubious approximations of market value. The price of Canadian en route control is equal to the square root of the aircraft's maximum takeoff weight multiplied by the great-circle distance between the origin and destination multiplied by a constant price factor. Domestic American flights entering Canadian airspace must pay NAV CANADA for the weight-distance flown in Canadian airspace.[44] Leaving aside the aforementioned irrelevance of weight to the market value of airspace consumed by the operator (although here, at least, operators are given diminishing marginal costs of weight from the square root component and thus less disincentive toward large planes than in American landing fees) it is clear that the distance component does not reflect the market value of the airspace consumed either. As with real estate, location, location, and location give a flight its value.

En route capacity is limited by the rate of handoffs between controllers at en route centers and by the physical miles-in-trail separation requirement. Centers route traffic through predetermined patterns over which the operators have little control, particularly during weather avoidance "playbook" routes. Market-based approaches at the en route level would price en route travel based on demand at that time, which translates to pricing based on how many other aircraft are in that sector (or in a particular traffic flow) at that exact time. It is hard to see how current technology would support this market-based approach. Center controllers have the ability to designate sectors as high-congestion (yellow "caution" light) closed (red light) on their consoles; it might be theoretically possible to charge operators entering high-congestion areas or to auction spots on congested routes and pass fees incurred along via the flight strip, but no effective solution is immediately apparent with existing technology.

Beyond the palliative effects of reforms at the landing-fee and ticket-tax levels, en route congestion will likely be relieved through innovative technology and not market-based reforms. Other methods of directly addressing bottlenecks at the TRACON and en route levels are necessarily contingent upon redefining separation standards and procedures and are therefore not primarily market-based, although any proposed technological reform involves market considerations.

General aviation and business jet operators, who operate the smallest planes, stand to lose the most from such adjustments; fortunately, GA and bizjets operate mainly from uncongested secondary and tertiary airports, which would not be affected by this proposed change. GA flights constitute only 8.2% of operations at the top 30 airports.[45]

Just as the ticket tax would promote airspace efficiency by connecting the operator's cost of ATC to the quantity consumed per passenger, the proposed change to landing fee structure would promote airspace efficiency by allowing the market to determine the cost to operators of consuming airport space. The effects of the two proposed reforms are similar: in both cases, airlines would increase per-plane capacity and decrease frequency of flights to congested airports. This consolidation effect would mitigate a major source of congestion, the current ubiquity of regional jets (RJs) at major airports. As AirTran CEO Jim Leonard testified to the House aviation subcommittee, "I don't understand how the overloaded air traffic control system will absorb the hundreds

[44] Applies to aircraft weighing 20 metric tons or more, though NAV CANADA vows to extend charges if America succeeds in billing Canadian first-freedom flights over America. American-controlled Canadian airspace is excluded from charge. See www.navcanada.ca for complete description.

[45] National Business Aviation Association, Inc. NBAA Business Aviation Fact Book 2004. 2004.

of RJs on order."[46] The proposed changes would also encourage operators who wished to continue flying low-capacity, high-frequency operations to use secondary airports not subject to the proposed changes.

In short, the overall effect of the proposed changes will be increased airspace efficiency: Operations servicing major airports will consolidate passengers into larger aircraft, and commuter service to regional airports will become a more competitive travel option. Although explicit costs to airlines from operations tax and landing fees at major airports must increase in the short term to correct the current capacity shortage, the implicit costs of delay will be much less.

[46] Aviation Week Space Technology. 21 June, 2004. p86. 'Viewpoint' adapted from Congressional testimony.

3 MODERNIZATION OF PROCEDURES AND TECHNOLOGIES

There are a number of technological and procedural advancements that could help to reduce congestion in the NAS. An effective plan of NAS modernization depends upon a selection of these technologies that will be most effective in supporting the modernization goals with a corresponding certification of the necessary procedures to take full advantage of those goals. The FAA should install software at control facilities and develop and certify procedures and incentives to give advantage to appropriately equipped aircraft, such as giving equipped aircraft first priority or providing air traffic control tax refunds, to expedite modernization.

The future NAS will exhibit better on-time performance, continued safety, and significant increases in efficient use of scarce NAS resources only if these concepts are incorporated into a modernization policy. These concepts shifting from the current navigation system to one in which users may fly directly from origination to destination, developing procedures that benefit aircraft with increased navigation and surveillance capabilities, using advanced satellite navigation and surveillance technology, automating routine and safety-neutral air traffic control operations, and implementing digital data link communication infrastructure.

3.1 Use of Direct Routes from Origination to Destination

The current NAS is built on a decades-old system of navigational aids requiring aircraft to fly from over one ground navigation aid to above the next. Aircraft lose a significant percentage of flying time and fuel to fly these indirect routes, and the airspace over the navigation aids becomes congested quickly, resulting in chokepoints in the system.

Flights traveling between sectors (”en route”) function like a system of interstate highways. Leaving an airport, flights take one of a few specific departure flows (much like on-ramps) and ascend to en-route traffic flows (much like highways). As the flights merge onto the en-route traffic routes, they enter the control of en-route centers. Just as cars on the highway ought not to follow one another too closely, centers space the merging aircraft according to miles-in-trail (MIT) separation standards. Chains of navigational beacons delineate the ”highways” that the aircraft follow. This highway-like routing system arose in the aviation boom following the Second World War and has not changed significantly since.

En-route center controllers merge multiple entering flows into a single en-route flow while preserving standards of safe separation. Traffic ”bottlenecks” occur at these points just as they might on highways. Likewise, congestion occurs at intersections of traffic flows, commonly over a ground-based navigational beacon.

The post-WWII system was designed in the days of airline regulation, when flights were few in number, coordinated to avoid congestion, available only to the wealthy, and controlled by primitive radar and simple radio communication. Today’s hi-tech world of deregulation, bargain-priced tickets, and mass air travel has rendered the old paradigm obsolete. In order to remain a safe and viable travel option, the NAS requires modern management procedures. Even under the constraints of the old model, the locations of the waypoint navigational Very High Frequency Omni-Directional Radio Range and Tactical Aid to Navigation beacons (VORTAC) defining the ”highway” routes were never optimal for flight-path efficiency. As with highways, many external factors cause the routes to deviate from shortest possible distances: land usage, availability of lend-lease agreements, geography, political influence, and so forth. At that time, aircraft were required to fly directly from one beacon to the next. With newer versions of these navigational aids, aircraft are able to establish their positions without flying directly toward a beacon.

Direct routing is the ability to fly a route directly from origination to destination, without making connections over VORTAC beacons. Many aircraft are equipped to fly direct routes, but air traffic control allows only limited use of direct routing procedures. Increasing the use of direct routing procedures should be a priority in NAS modernization. The FAA should expedite certification of direct routing procedures and encourage use of the same by air traffic controllers. Furthermore, because today's satellite technology enables planes to know exactly where they are without recourse to terrestrial beacons or landmarks, the essentially two-dimensional "highway" model will become completely unnecessary with the transition to satellite-based navigation.

Procedural changes must also be compelling enough to overcome the institutional resistance inherent in government bureaucracy. The term "traffic management" implies a greater degree of operator autonomy and a diminished role of the "controller." The National Air Traffic Controller Association (NATCA) is reasonably concerned that making changes to an already safe system may have dangerous consequences. NATCA must be convinced that its membership will be best served by greater pilot autonomy. Not only will the number of controllers needed not be fewer than needed now, but also the transition to an ATC system capable of supporting direct routing can be accomplished safely. Increased airspace capacity will permit increased airspace usage and increased demand for NATCA members, much as the computing revolution displaced menial arithmeticians but created many more jobs programming computers. A quickly enacted procedural reform can advantageously use a window of opportunity: in 1981 a large demand for air traffic controllers was filled with new hires. These replacements are now approaching the mandatory retirement age of 56 years. Because these controllers are willing and able to continue work professional pilots themselves are not required to retire until age 60 the federal government should temporarily extend the mandatory ATC retirement age. Such an extension would buy time to implement new traffic management procedures so that newly hired employees could be trained in the new procedures, thus circumventing much institutional resistance.

The FAA should continue development of direct routing systems for all control facilities. Currently, limited use of direct routes is allowed by air traffic controllers in certain situations. Historically, technology was not in place that could support direct routing capability, but today's technology does support direct routing. However, the language and operation of modern air traffic control is a holdover of the old technology constraints. The FAA should begin to develop the language of a future routing system, the language of latitude, longitude, altitude, and time coordinates. Area Navigation (RNAV) is the FAA's concept in support of direct routing. A significant percentage of commercial aircraft are equipped with RNAV capability. RNAV procedures can be based on Very High Frequency Omni-Directional Radio Range and Tactical Aid to Navigation beacons and satellite navigation technology. With RNAV capability, an aircraft is able to fly directly from origination to destination. This ability becomes especially helpful when specific routes reach capacity, due to weather or other factors. Aircraft with RNAV capability may negotiate a direct route with air traffic control in order to bypass the congestion. Similarly, the use of RNAV procedures allows aircraft to bypass weather. Consumers who use RNAV procedures will benefit from time and fuel savings, as well as the increased flexibility in route planning.

However, the old, standard routes have historical momentum, and air traffic controllers are familiar with their use. The primary barrier to RNAV implementation is its use of nonstandard routes. In many instances controller familiarity is the limiting factor to airspace capacity, and arbitrary routes would only negatively affect capacity by reducing the number of aircraft each controller can reasonably monitor. It is difficult to convince air traffic controllers to learn a new system when the current system has proven safe. Previous attempts to switch to an RNAV system of routes faltered for these reasons, but this doesn't mean RNAV is not a valid progression toward a modern NAS. Instead, RNAV was ahead of its time. ATC automation and other NAS modernization make RNAV a viable evolution in the future NAS. Therefore, the FAA must update the RNAV system in a form compatible with the current system, at the same time basing it on latitude/longitude waypoints, instead of navigation beacons, and more direct routing.

Some foreign airspace navigation service providers consider RNAV and direct routing vital to the NAS modernization. The availability of user-preferred routes is the top priority of Airservices Australia, the airspace navigation service provider for Australia, as well as a high priority of NAV CANADA, Canada's airspace services provider.[47] User-preferred routes should be a priority in the United States NAS as well.

In 2001 the FAA redesigned the Los Angeles center airspace for RNAV implementation, and the Las Vegas TRACON began using RNAV departure and arrival procedures. The savings resulting from RNAV implementation at Los Angeles center was estimated at $45 million in the first year.[48]

The FAA has published over 700 RNAV procedures since the inception of the RNAV concept, each differing by flight phase and control facility.[49] A number of RNAV routes have been created in Charlotte, NC, airspace, an area with particularly inefficient standards.[50] RNAV procedures should be published for all control facilities and flight phases. In the long-term, RNAV routes should be created for all of the NAS, entirely replacing the old routes and procedures by 2012.

More research into the safety of system wide use of direct routing is needed. For instance, air traffic controllers may not be able to maintain a reliable situational awareness if required to track the aircraft along arbitrary routes without reference to the old system. The FAA should certify RNAV procedures and take the steps necessary to ensure controller acceptance.

The transition to direct routing is smoother in countries like Canada and Australia because those countries have more dispersed traffic and a younger NAS, relying less on longstanding ground- based navigation aids. If the U.S. NAS does not overcome the difficulties of controller acceptance and equipping aircraft with the technological/procedure advancements enabling RNAV, it will not be capable to respond to the growth in demand and congestion.

3.2 Procedures for Advanced Surveillance and Navigation Capabilities

Separation Standards

The number of aircraft that can fit into a portion of airspace is determined by two factors: (1) the number of aircraft that air traffic control can support and (2) the distance aircraft must be separated from one another for safety purposes. Separation standards have not changed significantly in three decades, but in January 2005 vertical separation standards will be reduced from 2,000 feet to 1,000 feet through the FAA's Domestic Reduced Vertical Separation Minima (RVSM) project. This change literally doubles airspace capacity in some segments of flight where separation standards are the limiting factor. There also exists separation minima for lateral separation and Miles In Trail (MIT). These standards vary by flight phase en-route, terminal, and oceanic and weather normal weather and reduced visibility.

[47] See the Australian Air Traffic Management Strategic Plan and NAV CANADA's "Alternate Route: An Approach to Enhancing ATC System Capacity."

[48] "Blueprint for NAS Modernization 2002 Update." Department of Transportation Federal Aviation Administration. Chapter 6. <http://www.faa.gov/nasarchitecture/Blueprint2002.htm>. October 2002.

[49] Pate, Donald P. "RNAV Approaches" Presentation. Luxemburg. November 4-6, 2003.

[50] "RNAV Routes Through Terminal Airspace". Air Traffic Services Brief. Aircraft Owners and Pilots Association. <http://www.aopa.org/whatsnew/air_traffic/rnav.html>. 2004

More work should be pursued in understanding reasonable separation minima such as why there is a 5-mile separation requirement en route regardless of the relative direction of the aircraft. This work should be expedited, for it will have an immediate effect. The next revision of separation requirements should not take longer than a couple of years to come to fruition.

Efficient separation standards will vary by more than flight phase and relative aircraft weight. First, current separation standards do not take full advantage of technological capabilities. Aircraft equipped with advanced surveillance and navigation technology should be allowed to operate under different standards determined safe by the capabilities of that technology. There are some fleets in existence with three-decade old planes. With today's ATC technology, implementing a system of mixed standards is possible. Second, separation standards could, in some operations, be time-based - for instance, Traffic Management Advisory (TMA) uses time- based metering.

The FAA should re-evaluate required separation standards. The transition to new navigation and surveillance technologies allows for reductions in safe separation standards. RVSM will be a good first step in this process, but a comprehensive set of separation standards should also consider navigation and surveillance capability and specific operation.

Required Navigation Performance (RNP)

The idea of increasing the variability of separation standards can be extended to a comprehensive program of navigation procedures rated by navigation and surveillance capability. The International Civil Aviation Organization (ICAO) developed RNP to support RNAV procedures.

RNP rates aircraft according to their navigation capabilities. Aircraft with higher RNP levels gain access to procedures inaccessible to other craft (e.g., curved approaches, special RNAV routes, airspace not covered by radar) as well as reduced separation requirements. RNP certification standards account for availability, accuracy, integrity, and continuity and differ according to the phase of operation.

Some RNP procedures have been developed already. By developing more RNP procedures, the FAA will allow for the use of technology with increased precision, which will support terminal spacing and sequencing as well as surveillance and will increase the incentives for operators to equip advanced navigation and surveillance technology, because access to otherwise inaccessible procedures will increase on-time performance and save operators time and money. RNP standardization and procedures are important developments in the future of the NAS.

The FAA should also continue development of RNP procedures, available to aircraft meeting navigation and surveillance standards. The flexibility of these procedures to allow access to airspace routes which bypass congestion, operators will have renewed incentive to equip their aircraft with advanced technologies.

3.3 Augmented GPS Routing Procedures

The current navigation system will not meet the future needs of the NAS. To meet these needs, the system must be wholly replaced.[51] In order to accomplish this task, the future NAS will communicate location using latitude and longitude coordinates instead of standard routes and ground-based navigation beacons. Global Positioning System (GPS) hardware is the necessary technology

[51] A study by Booz Allen Hamilton on behalf of Australian Airservices claims this exactly concerning the Australian ATC (qtd. in The Australian Strategic Air Traffic Management Group. "Australian Air Traffic Management Strategic Plan 2003 - 2015 And Beyond." 2003. < http://www.astra.aero >). The sentiment is applicable to the U.S. NAS as well.

to support this transition. GPS[52] is a navigation technology built on 28 satellites maintained by the Department of Defense (DoD). An aircraft accesses four or more of these satellites to determine its three-dimensional location as well as time.

GPS has many benefits besides providing flexible location information not dependent on the standard route system. GPS is much more precise than VORTAC equipment - at least 10-meter accuracy versus approximately 60-meter accuracy. The system is also cheaper to maintain, and GPS supports RNAV capability because the aircraft can compare its own location with the known location of the destination. However, GPS alone is not sufficient for the navigational needs of the NAS. It must be augmented to meet accuracy, integrity, availability, and continuity specifications.

Wide Area Augmentation Systems (WAAS) improve the GPS location data by communicating with another satellite that compares the known location of a landmark with the GPS data. It communicates the resulting error correction to the aircraft. Local Area Augmentation Systems (LAAS) can be used near an important ground location, such as an airport. The control tower on the ground distributes error correction information locally. LAAS certification is projected for 2005. Two hundred forty approaches with LAAS equipped B727 and Falcon 20 aircraft have been completed successfully, and Federal Express has also begun to equip its aircraft servicing Memphis, TN, with LAAS and GPS landing capabilities.

Johns Hopkins University conducted a study to evaluate the ability of GPS technology to provide a "sole means" navigation capability and reported that the technology is sufficient as a "sole means" service provider.[53] Volpe National Transportation Systems Center issued a similar report that differed from the conclusions of the Johns Hopkins report in that certain barriers, including interference and degradation during critical phases of flight, remain. However, the Volpe report indicates that augmentation, redundancy, and/or procedural support for GPS technology could overcome these barriers, with different combinations for different situations.[54]

GPS is an additional technology for RNAV, advanced surveillance[55], and ATC automation[56], and is vital to the future NAS. GPS supports RNAV capability, because the aircraft can compare its own location with the known location of the destination.

However, airlines do not see bottom-line profit benefits by equipping their aircraft with expensive, new navigation technology. GPS also has only an indirect effect on efficiency and safety improvements, because it cannot yet be implemented as a "sole means" navigation and surveillance technology. If it could, radars and navigation aids could be decommissioned to reduce air traffic control costs. Radar, and to a lesser extent ground-based navigation beacons, will still be required even if GPS is in use throughout the NAS, to provide redundancy during transition. The transition, however, is becoming more cost effective, and as fleets become updated, eventually GPS will overcome the NAS. Equipping aircraft with GPS has also become more cost effective.

3.4 Incentives for Consumers to Equip Aircraft with ADS-B Technology

During poor weather and reduced visibility, aircraft depend on instrument navigation and surveillance instead of visual navigation and surveillance. The procedures and standards associated with

[52]For more information on the available navigation systems as well as augmentation methods, see chapter 3 of "Australian Air Traffic Management Strategic Plan 2003 - 2015 And Beyond," Volume 3.

[53]Corrigan, T. M., et al. "GPS Risk Assessment Study". Johns Hopkins University Applied Physics Laboratory. January 1999. < http://www.jhuapl.edu/programs/trans/gps/gps.pdf >

[54]John A. Volpe National Transportation Systems Center. "Vulnerability Of Transportation Infrastructure Relying On GPS". August 2001 < http://www.navcen.uscg.gov/archive/2001/Oct/FinalReport-v4.6.pdf >

[55]See the next section on ADS-B technology.

[56]See section 3.6.

normal weather conditions are known as Visual Meteorological Conditions (VMC), and with reduced visibility Instrument Flight Rules Instrument Meteorological Conditions (IMC). IMC flight restricts aircraft operations more than VMC flight, and the separation standards for IMC are increased. Weather and IMC conditions can sometimes halve the runway capacity because parallel runways are too close to satisfy the necessary IMC lateral separation standards. An important objective in NAS modernization is the increase of control abilities and surveillance during IMC conditions so that the restrictions are not drastically different from VMC condition restrictions. This reduction of IMC effects depends on the implementation of improved surveillance and communication technology, as well as the use of corresponding procedures. Automatic Dependent Surveillance-Broadcast (ADS-B) is such a technology.

ADS-B technology allows aircraft to distribute location, altitude, the next waypoint, etc. to other aircraft and air traffic controllers at short intervals over a direct data link. Airservices Australia, the air navigation service in Australia, suggests, "This new technology [ADS-B] promises radar like surveillance at significantly less cost . . . and eventually cockpit displays of adjacent aircraft."[57] Airservices Australia has an aggressive plan to implement ADS-B capability over all Australian airspace, and an ADS operational trial came online in 2004.

The greatest benefit of ADS-B technology results from widespread equipage. System-wide equipage yields significant cost-benefits - NAV CANADA estimates that ADS has saved them 50 percent of oceanic communication costs[58] - but unilateral equipage is currently worth little for a consumer. It is important for system integrity, however, that even the aircraft that find no economic value in equipage be equipped with ADS-B. It is suggested that 30 percent of the North Atlantic air traffic is ADS equipped[59], so equipage is possible if there are sufficient benefits. Over the ocean, radar surveillance of aircraft is minimal, so the use of ADS becomes more valuable in that airspace. Iceland implemented ADS-B technology under the successful Capstone project. Other ADS demonstrations have also proved successful, including projects in Alaska and the Ohio Valley. ADS-B service is supported in Bethel, Alaska; Memphis, TN; Louisville, KY; and other locations.

ADS is vital for many NAS modernization projects, including air traffic control automation (discussed elsewhere) because ADS technology gives ATC access to digital flight data from the aircraft, direct routing support because ATC can track aircraft with automatic functions increasing the ability to monitor more planes along arbitrary routes, and increased pilot situational awareness because ADS technology can communicate with other aircraft as well as ATC. ADS equipped aircraft take advantage of advanced RNP standards and procedures.

Traffic Alert and Collision Avoidance System (TCAS) is another surveillance technology that allows pilots to monitor nearby aircraft. Collision avoidance technology on each aircraft will help to replace pilots' eyes as well during IMC conditions. TCAS technology has been mandated for most aircraft, and it already provides many of the benefits that ADS-B offers. However, TCAS does not have important features of ADS-B technology, and ADS-B is necessary to enable the many projects discussed in this report.

Like GPS technology, consumers hesitate to equip aircraft with ADS technology, because of high cost and lack of near-term benefits. Further, ADS will not increase capacity, per se, nor will it directly effect efficiency - more so safety, but ADS is also an enabling technology for ATC

[57] Annual Report 2003. Airservices Australia.
<http://www.airservicesaustralia.com/profile/annualreports/areport03.pdf>

[58] "New Upgrade to Oceanic System confirms Gander Oceanic as World Leader". NAV CANADA
< http://www.navcanada.ca/NavCanada.asp?Language=EN
&Content=ContentDefinitionFiles%5CNewsroom%5Cbackgrounders%5C2002%5CGaats.xml >

[59] New Upgrade to Oceanic System confirms Gander Oceanic as World Leader".

automation and advanced pilot situation awareness technology. Multiple projects, domestic and foreign, have shown promise, and it is important to take the next step. The FAA should develop RNP procedures that benefit ADS equipped aircraft. For instance, where two ADS-B and TCAS equipped craft interact with each other, a separate, relaxed set of separation standards should be used.

3.5 Procedures and Incentives for Formation Flight

Formation flight is a WWII-era innovation that never crossed over into commercial aviation but could still prove useful in reducing en-route congestion. Formation flight offers benefits to en-route ATC and operators alike. Currently, ATC has few procedures for formation flight and only in specific situations (e.g., landing in two-craft formation and military formations). In this optional procedure implemented at the discretion of all pilots involved, a group of planes would be controlled as a single unit and directed to self-separate into a close pattern of flight. (The specific formation could be dictated by controllers or agreed upon by the operators). Pilots may use visual contact and the transponder-based TCAS system to assist in self-separation. Formation flight may be infeasible for passenger carriers, whose customers might not appreciate the increased noise or the novelty of seeing other passengers out the window, but in certain circumstances formation flight would prove a ”win-win” proposition to both operators and controllers: ATC would benefit from having only one unit to control where previously several aircraft required manual separation, while operators could also benefit from a slight reduction in fuel consumption. As an overall effect, formation flight would increase airspace efficiency by fitting several aircraft at the center of the zone of separation previously reserved for one aircraft.

We suggest that formation flight has not been widely accepted in commercial aviation for several reasons. First, formation flight is more difficult for pilots than normal flight.[60] If formation flight were to be used often, pilots might need advanced certification. Second, commercial formation flight might have a negative connotation in the minds of passengers, operators, and controllers. Finally, there has not been enough research conducted into the use of formation flight in commercial flight. The automation issues alone pose a potential stumbling block. For example, TCAS and GPS procedures would have to be revamped under a formation flight transportation system.

UCLA researchers in conjunction with Dryden Flight Research Center in Edwards, CA, have experimented with a two aircraft formation and estimated a fuel savings of 29% for the second aircraft.[61] UCLA researchers estimate that overnight package delivery services, such as FedEx, a quarter to a half million dollars per plane annually by implementing formation flight in its system.[62] These are studies that support one aspect of the benefits of formation flight: fuel savings, which can have benefits in certain situations such as cargo transport companies.

Formation flight would provide great savings to the NAS during severe weather situations that force traffic into congested flows. Flow along these routes could be increased by a significant percentage if groups of aircraft with similar paths are gathered into formations. While in formation, the air traffic controller need only regard the formation as a single craft, reducing work for the controller.

[60] See the article on AVweb at <http://www.avweb.com/news/airman/184315-1.html>.

[61] The lead plane was a DC-8 followed by an F/A-18. See the news release on the Dryden Flight Resear ch Center website <http://www.dfrc.nasa.gov/Newsroom/NewsReleases/2003/03-42.html>.

[62] AviationNow's Next Century of Flight Staff. ”To Save Fuel, Fly In Formation, Say UCLA Researchers ”. Aviation Week. July 17, 2001. <http://www.aviationnow.com/content/ncof/ncf_n34.htm>

Formation flight procedures could be a near term aid to increase en-route airspace capacity. Formation flying has been used safely by the Air Force, since the incorporation of aircraft in military operations yet limited procedures exist to allow an air traffic controller to give two aircraft performing parallel runway landings responsibility to self-separate. The procedure to create this "formation" requires significant work, especially on the pilots' part, but once the aircraft is in formation, the burden on the controller is reduced below the effort required to control two aircraft separately. Overall effort and load on the system is reduced.

The primary difficulty associated with developing formation flying procedures for en-route operations is the work required to construct and deconstruct formations with aircraft with slight differences in origination, destination, time of departure, and intended flight path. However, it is likely the case that enough similarities between flights, in whole or only flight segments, exist to increase capacity of congested routes by using formations. Sufficient research must overcome controller comfort issues and a detailed analysis of historic air traffic flows must prove that significant benefits can be achieved before the development of procedures can begin.

The FAA should provide incentives for formation flying. Specifically, a formation should receive tie-breaking priority in situations where either a formation or a single aircraft must be diverted such a priority is natural, since fewer operators are inconvenienced by the adjustment. The FAA should tax formation flyers less because they consume less ATC for such an operation. Since formation flight would be an optional procedure from which both controllers and operators benefit, the FAA should revise en route ATC procedures to offer the option of formation flight to similar aircraft concurrently traveling the same trans-Atlantic, oceanic, or transcontinental route.

3.6 Integrated Displays and Computation for Ground Control Facilities

Many technologies are available and under development to support the work of the air traffic controller. Each supports ATC tasks in one or more of three categories: data acquisition and management, decision making, and execution.

In the first task of data acquisition and management, flight information is gathered and displayed for the controller. The data can be abstracted in a number of configurations to make the display more useful to the controller. Controllers historically use "flight strips" flight number, origination, destination, altitude and other useful information printed on strips of paper in combination with radar surveillance and voice communication with the pilot to track aircraft. Other information (such as sector boundaries, flight data, and even conflict abstraction) can be integrated with radar surveillance on the display, allowing controllers to comfortably control more aircraft. Furthermore, technology exists that enables the integration of more controller aids via surveillance, flight data, and communication. The second task, decision making, is primarily accomplished by the controller alone. Programs exist that assist the decision maker by recommending final approach sequence, monitoring conformance to the intended flight path, detecting potential conflict between aircraft, and highlighting important features of the situational data. Finally, execution, the third task, is performed via voice communication between the controller and the pilot over VHF radio. Execution and information gathering can both be expedited by using digital communication.

Before discussing these steps in detail, it is important to consider the controllers and current tools. Capacity constraints often depend upon controller comfort and ability to such an extent that other constraints, such as miles-in-trail separation necessary for aircraft to avoid wake vortex effects, are rendered ineffectual. The solution is not always to assign more controllers, because additional controllers increase the challenge of maintaining common situational awareness and efficient collaboration between controllers. Often, even the rate at which controllers are able to "hand off" an aircraft between controller jurisdictions is the predominant constraint. This "hand-off" is normally executed by passing paper flight strips. Often, one controller walks across the room to another controller to hand him or her the flight strip, or if he/she are not in the same room, the first controller will scan the flight strip, which is then reprinted for the second controller. Only recently did Philadelphia International Airport replace the policy of dropping the flight strip into a PVC pipe connecting the control tower with the TRACON directly below. Such a system requires an unmanageable number of controllers in proportion to the number of aircraft under control in order to sustain any increase in demand. Because of the controller comfort needs, increased capability of surveillance and navigation technology is not supported, eliminating the incentive for consumers to equip advanced technology.

Currently, "[w]ithin a given area, the controller is provided with a workbench containing the basic tools of voice communications, flight data strips, and radar display. The tools provide and transfer raw data but they do not add value to the data nor is there a way to readily assess the impact of actions in one area of responsibility on the system. Current flow management systems and procedures provide an often inexact overlay that is not well integrated with the rest of the system."[63] In the future NAS, information should be transmitted efficiently and automated systems should be installed to manage information for the controller, eliminating the need for manual flight strips and reliance on voice communication.

It is difficult to model and automate air traffic control decision making tasks because of the complexity of air traffic and the variability of situations that a decision maker confronts. The human decision-maker has proven well-suited to managing air traffic reliably by maintaining a mental model of the situation, simplifying complex information, and reacting intelligently to new problems. However, rigid standards, such as separation requirements, can be monitored by a computer. The computer can alert the controller if a conflict is detected or predicted.

Inefficient execution, like inefficient information gathering, can slow the responsiveness of the system. First, with increased traffic congestion, the bandwidth used to carry voice communications between pilots and controllers becomes congested. Second, single-channel voice communication is sluggish and prone to error. Again, controller workload becomes the limiting factor for demand upon the system. A single mistake, mumbled word, or misunderstanding between the pilot and controller can have drastic consequences. In contrast, a digital system could communicate with a greater number of users at the same time, and automation could maintain the communication of standard information, leaving the controller to vital decision-making tasks. In order for the computer to provide this role, the situation must be translated into digital language. The use of flight strips and voice communication is incompatible with a digital version of situation awareness.

In the future NAS, not only must information be distributed quickly, but decisions must also be executed quickly and reliably. Moreover, the language of air traffic control must be replaced with a new one. To facilitate the transition to RNAV and direct routing prevalence, air traffic controllers must begin to describe an aircraft's position in reference to the four dimensions of latitude, longitude, altitude, and time, instead of referencing well-defined routes connecting at ground navigation beacons.[64] Today's experienced controller has, over time, become intimately acquainted with the map composing his or her sector, memorizing the shape of its boundary as well as the

[63]"Alternate Route: An Approach to Enhancing ATC System Capacity". NAV CANADA . <http://www.navcanada.ca/ContentDefinitionFiles/technologySolutions/AlternateRoute_en.pdf>. October, 2001

[64]It could be very hard to do in speaking - requiring some sort of short hand, but one could use decimal latitude and longitude in degrees (e.g., 32.33 deg) instead of degrees, minutes, and seconds (32 degrees 20 minut es 20 seconds).

routes into, out of, and within that boundary. This controller depends on a mental model of the air traffic, the routes, the boundaries, and any applicable rules to maintain safe control. Such a system is not robust to increase in demand; neither is it robust to the use of undefined paths.

RNAV has proved difficult to implement because of a lack of controller acceptance; controllers are comfortable with the current language of air traffic control and are reluctant to change. Air traffic automationinformation integration, support for decision making, and executionis necessary before NAS users can stop relying on traditional navigational aids and routes.

For the future NAS to be primarily limited by avionics-based separation standards and not controller workload, the automation of data communication, display of integrated data, and decision-making aids are vital advancements. ATC automation will facilitate other important NAS modernization tasks as well.

The User Request Evaluation Tool (URET) is a technology under development by the MITRE Corporation since 1995. URET automates information gathering, allowing the controller to edit flight data electronically - as opposed to revising flight strips - and detecting conflict between aircraft. The primary focus of URET is allowing controllers to respond to certain pilot requests quickly, giving them time to concentrate on other things. URET has also been shown to reduce the number of separation restrictions imposed by controllers.[65] URET cost an estimated $300 million to develop and deploy. It is a major step toward ATC automation, and has proven effective. URET has been in use at Indianapolis Center since 1997 and has saved airlines at that center over $1 million annually.[66]

As noted below, the Center-TRACON Automation System (CTAS) has encountered less success than URET. CTAS supports the decision-making task and is composed of two systems: Traffic Management Advisor (TMA) and passive Final Approach Spacing Tool (pFAST). Traffic Management Advisor aids the controller by organizing and scheduling aircraft in preparation for landing. It suggests waypoints and schedules landing time. TMA improves arrival rates at peak congestion times anywhere from 3 to 6 operations per half hour for Minneapolis and Dallas-Fort Worth airports.[67]

Increasing efficient use of runways and terminal space motivates pFAST. In the best scenario, assuming an infinite queue of aircraft preparing to land, runway infrastructure has a maximum utilization of 10 percent.[68] pFAST maximizes utilization by precisely spacing aircraft according to safe minimum distances for landing, beginning in the en route airspace and increasing in precision as the airplane approaches. For instance, when an aircraft crosses a waypoint determined by the controller, its estimated time of arrival should be within a specified allowance of the standard determined by the controller. Similar specifications will be assigned to each aircraft in the landing queue. As aircraft meet goals, the specifications will become more specific and the landing sequence more exact, starting in en route airspace.

At Dallas-Fort Worth airport pFAST's benefit is estimated at 2.5 additional arrivals per hour.[69] The intention had been to expand the project to include active FAST after testing and approving passive FAST. pFAST was scheduled for use at six TRACONs across the nation. However, the FAA has cancelled the project for the time being. Though controllers found the software produced some benefit, an active version would too aggressively automate the decision-making task from the controllers' perspective.

[65] "Free Flight Phase 1 Technologies: Progress To Date and Future Challenges." Department of Transpor tation Federal Aviation Administration. Report Number AV-2002-067. December, 2001.

[66] Free Flight Phase 1 Technologies: Progress To Date and Future Challenges."

[67] "Free Flight Phase 1 Technologies: Progress To Date and Future Challenges."

[68] "Alternate Route: An Approach to Enhancing ATC System Capacity."

[69] Free Flight Phase 1 Technologies: Progress To Date and Future Challenges."

The FAA has suggested, "[t]he more complex automated controller tools have made only modest capacity improvements at some locations and have proven to be far more difficult and costly to develop than anticipated."[70] NAV CANADA estimates CTAS will benefit runway throughput by about 5 percent.[71] Funding for FAST has been stopped. Though CTAS is, in principle, a useful progression in the evolution of ATC modernization, and a 5% improvement can be a significant improvement in certain situations, the hurdles that need to be overcome to implement CTAS are too great for the benefits to validate aggressive investment. The hurdles are primarily associated with the FAST component of CTAS; TMA is a low-cost system with a 5% to 10% marginal benefit.

In 1998 the National Research Council recommended automating high-level traffic control operations, such as data integration and display, conflict detection, and separation monitoring.[72] Further, it suggests automation systems include function to aid controllers in spacing aircraft for final approach and landing phases. These recommendations remain valid, and since that report was published, domestic and foreign pilot programs and studies prove the benefits of air traffic control automation. In the future, controllers will need access to highly automated systems. Flight data will be automatically displayed in an abstracted and clear way, separation and conformance monitoring will be automatic - monitored by the controller - and the system will flag all important abnormalities to standard operation. Pilots will be highly involved in the process. The controller will cease to control and will begin to manage air traffic. This future air traffic control will be achieved by many evolutionary steps. Presently, the technology necessary for the next system step in this evolution is available or in development. This technology needs to be certified and put into operation, but before that can happen, human factors issues must be resolved and air traffic controllers must cooperate in the transition.

ATC automation will enable increasing NAS efficiency by permitting direct routing capability, as well the possibility dynamic restructuring of sectors in the long term - each considered highly important by foreign air navigation systems. Furthermore, an automated ATC makes the NAS robust to increasing demand.

The NAS has yet to see substantial effects from a balanced investment in ATC automation. The FAA should support the evolution of air traffic control automation by investing in proven and necessary technology, fully automating data integration and execution while adding functionality to support decision making.

The technology exists to satisfy many important steps of the modernization evolution. These technologies also have years of supporting evidence. These steps include the complete automation of information gathering and execution as well as supporting the controller in the decision-making task by making simple recommendations and flagging important situational information. Decision-making automation will become easier to implement after expansive implementation of these first steps, assuming the technologies of the first steps are built with a mind toward the future.

With regard to data collection, the FAA should install data link[73] equipment at control facilities and ADS ground stations to insure nationwide coverage. Further, aircraft equipped with these capabilities should receive benefits, such as priority in restricted airspace. Airservices Australia charges ATC fees based on rates varying by airport, and from these fees includes deductions for aircraft with vital technology advancements. As part of an ATC pricing structure overhaul, the

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[70] *ibidem*

[71] "Alternate Route: An Approach to Enhancing ATC System Capacity."

[72] Wickens, Christopher D., et al. ed. National Research Council. "The Future of Air Traffic Contro l: Human Operators and Automation". The National Academies Council. 1998.

[73] See Section 1.7 about CPDLC.

FAA should consider similar discounts for aircraft equipped with necessary technology. The FAA should also update terminal and TRACON facilities with the capability to edit flight data electronically. Technology suitable for this task is in use in foreign air traffic control systems and can be adapted to the U.S. system. With regard to decision aids, the FAA should expand installation of URET to include all en-route facilities. Finally, terminal and TRACON facilities should be given the ability to execute routine actions automatically, relying on digital communication instead of voice communication.

Innovative air traffic control automation systems will yield gains in productivity. These systems should be built on a modular basis using a common architecture and operating system. With such a system, it will be easy to update and replace the system with new software and add other components. The technology for the first steps of air traffic control automation has been under development in the U.S., and it should be certified and installed at control facilities as soon as practicable.

It is important to keep staffing and safety concerns in mind. With the pressing need for training air traffic controllers in the near future (because a large percentage of air traffic controllers are retiring over the next decade), this is the time to begin training young controllers in the use of newly automated systems. The new generation of air traffic controllers is ready for automation, growing up with video games, computers, and the internet.

All NAS stakeholders should understand the importance of investing in the implementation of advanced controller aids and automatic procedures to support NAS modernization. ATC modernization is a foundation for other major goals. The FAA must expedite the certification of any ATC technology with the cooperation of NATCA. The following are human factors issues to be overcome in the successful implementation of URET: "Acceptance, workload, and teamwork; instances when controllers must revert back to paper flight strips; Integration with TMA, Data Link, and new weather products."[74] And, "Controllers we interviewed at Memphis and Indianapolis Centers who have experience with URET were generally supportive of efforts to use electronic flight data."

3.7 National Platform for "Data link" Information Exchange

Equipping the majority of aircraft with digital communication capabilities is vital for NAS modernization in the long term. Data-link capability will support air traffic control automation because the pilot's console could communicate directly with the controller's computer. Further, a single data-link system could transmit communication for several purposes, such as ADS broadcasts, controller-pilot communication, weather data, and traffic advisories. Without widespread digital data-link capability, priority NAS modernization projects[75] will be extremely difficult if not impossible.

Currently, controllers communicate with aircraft crews through a limited Very High Frequency (VHF) range. VHF bandwidth utilization, already close to maximum capacity, is rising. Upgrading to digital data links will increase capacity. For each air traffic control sector in the NAS, an independent frequency must be assigned that does not overlap with frequencies of nearby "in-range" sectors. The growing number of sectors and air traffic activity combined with the limited assigned frequency range foretells a limited future for the current air-to-ground communication system.

[74] "Free Flight Phase 1 Technologies: Progress To Date and Future Challenges."

[75] Such as direct routing, ADS, and air traffic control automation.

Voice communication is prone to errors. Digital data link technology will not be affected by mumbled commands or misunderstanding, and weather avoidance will increase safety. Digital data link will have an error rate associated with it, but error correction technology has the ability to eliminate most errors over a data link.

According to a 2002 GAO report on the NAS[76], the FAA realizes its future ceiling on communication frequencies and has planned accordingly. Its solution is a multiphase program, culminating in 2009 with VHF Digital Link Mode 3 (VDL-3), a technology that allows the transfer of digital voice and data and supports the projected future demand of air-to-ground communication in the NAS.[77] This VDL-3 technology not only solves the problem of voice communication frequency range supply, but it also increases the amount of digital data that can be transferred to the cockpit. Pilots with more information at their fingertips will be better prepared to make decisions that optimize their flight path.

VDL-3 is not the only data link technology. In fact, similar data-link technologies have already passed testing and are in limited usage. There is not an agreed standard technology for data link connectivity. The FAA should cooperate with the International Civil Aviation Organization (ICAO) in order to establish a standard for data link technology.[78]

A disadvantage of a digital data link is that it does not allow controllers and pilots to monitor voice traffic, a major aid for situational awareness. Situation awareness, though, will be enhanced by collision avoidance technology already installed on most aircraft and technology based on the ability to distribute more information over data a link, such as weather and flight data of nearby aircraft.

Cockpit Display of Traffic Information (CDTI) is a technology developed to integrate and display information in support of pilot needs. CDTI displays weather, flight information of other aircraft from ADS broadcasts, and air traffic reports, and it even allows the pilot to monitor voice communication.[79] CDTI is similar to an enhanced version of collision avoidance technology, and it could be used for an aircraft to maintain its own separation from other aircraft. More information in the pilots' hands will allow distributed decision-makers in the NAS to coordinate decisions and react to changes more effectively.

Similarly, giving pilots access to a live map of surface movements at the airport where they are taxiing could mitigate some ground movement delays.[80] At the same time, it would be useful for the controller to access intent and identification information while using relevant automation. Such a technology would allow aircraft to taxi under zero visibility, thus helping to avoid delays associated with zero ground visibility. As previously mentioned, reducing the differences between IMC operations and VMC operations is an important goal in NAS modernization, and limiting the effects of ground visibility in this way is one step towards that goal.

Increased access to information will support pilots' ability to optimize their flight paths by analyzing upcoming weather and congestion. They can then amend their flight paths accordingly, allowing the controller to accept changes electronically. The appropriate procedures to support this communication between pilots and controllers are also necessary, encouraging quicker response to changes in weather and traffic, and saving operators time and fuel.

Airlines, attempting to maximize profits, will have more incentive than air traffic controllers

[76] U.S. GAO. "National Airspace System: FAA's Approach to Its New Communications System Appears Prudent but Challenges Remain." GAO-02-710. Washington, D.C. July 2002.

[77] *ibidem* p3-4

[78] "Australian Air Traffic Management Strategic Plan 2003 - 2015 And Beyond" suggests Mode-S is the likely future standard

[79] "Alternate Route: An Approach to Enhancing ATC System Capacity."

[80] *ibidem*

to learn and take advantage of data link technology and its associated operating procedures. Controllers, whose main concern is aircraft safety, may not optimize every aircrafts' route in their sectors. Therefore, pilots who use the technology to optimize their flight plans will gain decided advantages over pilots who do not optimize their flight plans through Collaborative Decision Making (CDM). Those pilots who optimize their routes will save their employers time as well as fuel.

American Airlines is participating in data-link demonstrations at Miami center with two dozen 737 aircraft, and four American 767s in Europe are equipped with data-link capability.[81] To encourage further operator equipage, data link technology should be installed at all air traffic control centers.

3.8 SWAP Procedures, Route Closure, and Weather Forecast Distribution

In a report on the gridlock in the NAS, the Air Transport Association Departments of Air Traffic Management and Economics states:[82]

> "The FAA frequently blames ATC delays on 'weather' and they do not focus on the real issue: management of how weather affects the system. The FAA has stated that in 1999, almost 72% of delays to aircraft that were 15 minutes or longer, were caused by weather and that, consequently, most of them were out of the FAA's control. However, through the proper use of weather forecasts and appropriate FAA decisions, the number of weather-related delays could be reduced dramatically."

Ground Delay Programs

Benefit could be gained from responding to changes in weather more quickly and updating ground delay programs more quickly. New weather forecasting abilities are becoming available, which should help the situation. Ground Delay Programs (GDP) are the most widely used tool for controlling flow in a delay situation. The FAA collaborates with NAS stakeholders to discuss weather forecasts every two hours as part of Collaborative Decision Making (CDM) and publishes the system-wide response to severe weather, sometimes in the form of a GDP. "Prior to CDM, the Air Traffic Control System Command Center (ATCSCC) did not have the capability to revise a program once it was in effect."[83] A 1999 MITRE report concludes that the FAA is slow in responding to changing weather and, thereby, slow in changing weather-related imposed limitations. Eighty percent of delay is departure delay - some due to GDP required by weather and some due to inefficient GDP usage.[84] Similarly, "In some instances it appeared that traffic supervisors were expecting either IMC conditions or high winds to continue and instituted a GDP, when in fact the decreasing capacity due to weather never materialized or ended abruptly."[85] Continued research should study the effectiveness of current policy regarding weather-related congestion.

[81] "Air Traffic Control: Role of FAA's Modernization Program in Reducing Delays and Congestion." General Accounting Office. GAO-01-725T. Washington, D.C.: 10 May 2001.

[82] Air Transport Association Departments of Air Traffic Management and Economics. "Ag Gridlock Air Traffic Control Delays." October, 1999

[83] CDM final report". Department of Transportation Federal Aviation Administration.

[84] Mafera, Paul, and Kip Smith, Ph.D. "Traffic Flow Management: ATC Coordinator's Information Requirements for the NAS." Human Factors and Experimental Economics Laboratory Kansas State University. March 2000.

[85] Allan, Shawn S., and Stephen G. Gaddy. "Delay Reduction at Newark International Airport Using Terminal Weather Information Systems" Massachussets Institute of Technology, Lincoln Laboratory.

Weather Data Distribution

For longer-term, strategic weather forecasting, a large amount of communication between NAS stakeholders allows weather problems to be avoided and "plays" from these playbooks to be called. Through a telephone conference, available stakeholders interpret the predicted weather information and collaborate on potential solutions to the problem. According to Nadine Monaco of *The MITRE Digest* , "This [ability to conference] allows them to plan traffic management initiatives and mediate potential delays before they happen."[86] Having this united response to daily weather fluctuations greatly reduces their negative effect on the NAS.

Despite collaboration, severe weather still plagues the NAS. Furthermore, according to the FAA, "The flexibility to adjust to severe weather conditions has disappeared at all levels in the NAS as demand has grown to fill capacity at key airports."[87] When a storm is only a threat to en route traffic, for example, there usually exists an ample volume of airspace that can provide at least one option for every aircraft in the sky to reach its destination. If real-time (or close to real-time) information is given to pilots, they will use CDM to find a detour more quickly than they otherwise could. Therefore, increased weather data in the cockpit will allow the CDM system to reach levels of greater efficiency in the NAS.

The ATC system also has difficulty quickly reopening routes in response to weather changes, as illustrated by the following statement from October 14, 1999, by Carol B. Hallett, President and CEO of the Air Transport Association of America, before the Subcommittee on Aviation, Committee on Transportation and Infrastructure in the House of Representatives, Hearing on Air Traffic Delays on October 14, 1999:

> "On the morning of July 31st, the FAA Air Traffic System Command Center (ATCSCC) began planning for how the ATC system would respond to a line of thunderstorms forecast for mid-afternoon extending from Buffalo to Kansas City. The collaborative forecast (meaning a number of airlines had participated along with FAA in its development) estimated that between 25 percent and 50 percent of this area would be covered that afternoon by thunderstorms and that the probability of the storms occurring as forecast was somewhere between 40 percent and 69 percent. This would indicate that the development of the storm required close scrutiny because there was a good chance that the storms would NOT impact the total area between Buffalo and Kansas City, and that the total area would not be denied for airline use. "But, apparently, this real-time tracking of the weather's development did not happen. Consequently, numerous opportunities for relief from the punishing ground stops that FAA had imposed, which assumed total coverage by storms, were not taken advantage of, even though there were large holes in the line of thunderstorms. The government's system presumed the worst, and 700 airline flights were delayed, many over four hours and many needlessly, because the system ignored the real-time development of this line of thunderstorms. This scenario has recurred all too often this summer and is one of the two major causes for unnecessary delays. Statistically, all of these 700 delayed aircraft were caused by weather according to FAA. The genesis of these delays was weather, but the majority of these delays were caused by FAA's mismanagement of the severe weather avoidance process. The ATCSCC [ATC System Command Center] did not exercise its necessary command and control authority over regional en route centers, truly the sole reason for its existence."

[86] Monaco, Nadine. "Making the Schedule." The MITRE Digest. 18 June 2002. Accessed 18 Aug. 2004. <http://www.mitre.org/news/digest/archives/2002/making_the_schedule.html>.

[87] FAA Report AV-2002-067. "Free Flight Phase 1 Technologies: Progress to Date and Future Challenges." 14 December 2001. p23.

Stakeholders need to revamp the process of reopening routes after they have been closed due to bad weather. Since most pilots have inferior information in comparison, why do pilots take action in opening routes before the FAA? If the FAA has an information advantage, it should be the first organization to realize that certain routes can be reopened. Otherwise, cockpits should receive updated weather information so pilots are better equipped to make "pathfinder" decisions. Digital data link technology will support the distribution of tactical weather information, allowing NAS stakeholders to respond to severe weather quickly and effectively.

Finally, there are a number of examples demonstrating the importance of updating Ground Delay Programs in response to weather changes. One example on February 12, 1999, shows that over a million dollars was lost because a GDP was not monitored and stopped soon enough. Another example regarding May 19, 1999, estimates the overextension of a GDP based on low visibility by 90 minutes cost $170,000. There were 50 other similarly low C&V days during that year, and, if only 20 of them encountered a similar overextension, the cost is $3.5 million.[88]

[88] Allan, Shawn S., and Stephen G. Gaddy. "Delay Reduction at Newark International Airport Using Terminal Weather Information Systems" Massachussets Institute of Technology, Lincoln Laboratory.

SUMMARY OF RECOMMENDATIONS

<table>
<tr><td>CATEGORY
TIME FRAME</td><td>SHORT TERM
(1- 3 YEARS)</td><td>INTERMEDIATE TERM
(4 - 10 YEARS)</td><td>LONG TERM
(> 10 YEARS)</td></tr>
<tr><td>Regulation and Legislation</td><td>Reform FAA operations tax

Extend mandatory retirement age for air traffic controllers</td><td>Deregulate landing fees

Eliminate slot control

Lift Department of Transportation (DOT) code-sharing restrictions

Relax foreign ownership restriction on US operators</td><td>Negotiate reciprocal treaties permitting fifth-freedom commercial operations</td></tr>
<tr><td>Infrastructure</td><td>Increase consumer awareness of alternatives to major airports</td><td>Incentivize use of regional airports and general aviation

Adapt runways/taxiways for simultaneous vertical/short take-off and landing (V/STOL), assuming these options are viable

Develop ground transportation support services</td><td>Construct new runways where needed

Create more comprehensive V/STOL infrastructure</td></tr>
<tr><td>Technology and Procedures</td><td>Support research and development in unconventional aircraft, such as V/STOL and mass transit seaplanes</td><td>Create procedures and incentives for formation flight

Continue research to advance weather forecasting and improve responsiveness of weather avoidance procedures

Install displays integrating all sources of flight and environment information at control facilities

Develop direct routing procedures for all control facilities

Develop augmented GPS routing procedures at all control facilities with incentive structures for equipage

Re-evaluate distance-based miles-in-trail separation standards

Incentivize operator equipage of ADS-B system

Build a national platform for "data link" information exchange</td><td>Develop distributed decision making technology and procedures</td></tr>
</table>

ELABORATION OF RECOMMENDATIONS

The following section is a summary of the recommendations listed in the above table. The following recommendations can and should be implemented within three years:

- **Reform FAA operations tax.** Current prices of Air Traffic Control (ATC) for passenger and cargo operations, consisting of flat-percentage rates on ticket fares and transportation fees, are distorted by aircraft size, load factor, connecting status of flight, and carrier's business model, and rates are insensitive to time- and location-variant demand. This price distortion causes inefficient allocation of scarce airspace. We recommend that the FAA adopt one tax system for all commercial operations, and that operators themselves (not passengers) be taxed on a per-plane, per-time, per-location basis. The resultant increase in revenues should be directed towards research and development and towards increasing capacity.

- **Extend mandatory retirement age for air traffic controllers.** Because most air traffic controllers were hired after the illegal PATCO (Professional Air Traffic Controllers' Organization) strike of 1981, many air traffic controllers are now close to the mandatory retirement age of 56 years. Because it would be difficult to hire and train enough new controllers in time, and since these controllers are largely willing and able to continue work professional pilots themselves are not required to retire until age 60 we recommend that the federal government temporarily extend the mandatory ATC retirement age. The extension would also buy time to develop and implement new traffic management procedures so that newly hired employees could be trained in the new procedures, circumventing institutional resistance.

- **Increase consumer awareness of alternatives to major airports.** The general public is prone to assuming that commercial travel from a major airport is the fastest or most cost- effective means available. However, taking into account total time spent in travel, many popular commercial routes average less than one hundred miles per hour. The DOT already reports information comparing the performance and customer service of major airlines, airports, and routes; we recommend that this information also be offered in the context of alternative means of transportation where available, e.g., railways, roads, and general aviation.

- **Support research and development for V/STOL and seaplanes.** These aircraft have future potential in revamping the NAS's infrastructure, but not as they exist today. Increase research and development in these aircraft so their technologies may someday be utilized.

The following recommendations can and should be implemented within the next ten years:

- **Deregulate landing fees.** Landing fees are limited by local and municipal regulations, artificial price controls on airport operations which create excess demand for use of major airports. Delay pricing, a much less desirable form of pricing laden with negative externalities, arises from this shortage. The federal government should leverage existing subsidies, including airport improvement funding and tax exemptions, to deregulate landing fees at the thirty-one major airports, deregulation both in scale (the amount an airport charges the operator) and structure (to a per-plane, not a per-pound, price structure). Any short-term increase in revenue should be directed towards improving capacity and technology.

- **Eliminate slot control.** If above regulatory reforms are adopted, slot control will no longer be necessary. Slot control is undesirable as an allocation system because of aggregation risk, which further artificially depresses the price of operations. It also operates as a barrier to new entrants, preventing competition.

- **Lift DOT code-sharing restrictions.** The DOT currently imposes an irrational restriction on the number of code-shared flights between hubs controlled by different carriers. Since code-sharing does not legally allow price- or output-coordination, this restriction is demonstrably detrimental to the consumer, who stands to benefit from the wider range of destinations and lower fares historically resulting from code-sharing.

- **Relax restrictions on foreign ownership of domestic operators.** As many airlines are on the brink of bankruptcy, a protectionist 25 percent cap on foreign ownership is an undesirable restriction on investment in domestic airlines. This restriction should be relaxed to 49 percent in the intermediate range, but long-term negotiations to ensure the reciprocal ability for American investors to own foreign domestic operators are needed before foreign-owned operators should be allowed fifth-freedom (i.e., US domestic) operations.

- **Incentivize use of regional/General Aviation (GA) airports.** A large number of under-utilized runways exist in populated areas served by regional and GA airports. This additional concrete should be utilized as much as possible by commercial aviation services. Care should be taken to address landowners' objections to commercialization of these airports. Starting soundproofing projects and regulating airplane emissions will help ease local concerns.

- **Adapt runways/taxiways for simultaneous Vertical/Short Takeoff and Landing V/STOL uses.** Large runways can potentially be treated as consecutive smaller runways to enable simultaneous landing and take-off of aircraft that require less runway length, such as STOL airplanes. Researchers should analyze the potential possibility of this type of STOL runway. If deemed advantageous, airports should update taxiways and other infrastructure to accommodate this method of runway usage. Furthermore, airports should consider adding supporting "vertiport" infrastructure to alleviate commuter traffic at the main airport, assuming that air transportation alternative is proven feasible.

- **Develop ground transportation support services.** Improving access to other forms of transportation will distribute air traffic congestion across alternative methods of transportation. Encouraging the creation of added ground transportation infrastructure will allow ground transportation operators to offer more alternatives to consumers. Eliminating regulatory barriers preventing airlines from owning feeder infrastructure (e.g., light rail) will allow airports farther from population centers to serve a greater portion of the public, reducing road congestion and encouraging airport expansion, since airport expansion is less feasible in densely populated areas.

- **Create procedures and incentives for formation flight.** Optional formation flight procedures, where pilots can use visual self-separation or collision-avoidance automation, would enhance airspace efficiency by fitting multiple planes within one zone of separation. En-route controllers would benefit from the procedure's consolidation of the units that must be controlled. Operators would benefit from increased fuel economy and we recommend additional incentives in the form of tax breaks on operations.

- **Continue research to advance weather forecasting and improve responsiveness of weather avoidance procedures.** Weather is the most significant source of delay, and the manner in which the FAA responds to changes in weather can compound the problem, often allowing weather-related restrictions to overrun their usefulness. Researching advanced forecasting products and the procedures using weather technology to come up with an effective response should be continued. Ground Delay Programs (GDP) should be evaluated according to their effectiveness and timing, paying special attention to the value of increased communication between controllers and pilots and the widespread distribution of weather information.

- **Install displays integrating all sources of flight and environment information at control facilities.** The transition to a direct routing paradigm is unsustainable because of current, manual methods and controller acceptance. New controllers should be trained to use a semi-automated system, which integrates flight data and surveillance data on a common display, incorporates digital communication between the pilot and controller, and uses automated aids to predict potential conflict and track aircraft conformance to intended flight path. The necessary technology to gather this data will also need to be developed. This automation will support the transition to direct-routing, use of more precise navigation and surveillance technology, and increase traffic control efficiency. System-wide implementation of User Request Evaluation Tool (URET) is the first step in the transition to a digital, semi-automated air traffic control system. Install URET at all en-route control centers.

- **Develop direct routing systems for all control facilities.** Access to at-capacity routes based on a decades-old navigation system, where traffic is funneled along well-defined routes and over ground-based navigational aids, is highly restricted during severe weather. The FAA should continue to develop procedures to allow aircraft to use arbitrary, direct routes connecting departure and destination to bypass these congested routes and connections. Aircraft flying directly will also save time and fuel. The use of direct routing procedures should replace the current routing system as the primary routing system in the next decade.

- **Develop augmented Global Positioning System (GPS) routing procedures at all control facilities.** Operating and repairing ground-based navigation aids is a financial burden on the FAA. Aircraft must be equipped with GPS technology to use advanced surveillance technology and to communicate 4-D flight data latitude, longitude, altitude, and time over digital data links, a capability necessary for increased situational awareness and automated ATC. Augmented GPS usage should be certified nationwide and the FAA should develop procedures specific to GPS equipped aircraft.

- **Re-evaluate required separation standards.** The transition to new navigation and surveillance technologies allows for reductions in safe separation standards, particularly in transoceanic routes not controlled by radar. The FAA should continue development of advanced procedures, including reduced separation standards, available to aircraft meeting navigation and surveillance standards, not only varying by flight phase.

- **Incentivize operator equipage of Automatic Dependent Surveillance-Broadcast (ADS-B) system.** ADS mitigates the capacity-reducing effect of weather, the largest cause of delay by allowing pilots and controllers to behave as if visibility were high. ADS-B technology also facilitates the implementation of other important modernization concepts, such as direct routing and enhanced situational awareness for pilots, and ADS will increase the safety of the NAS. The FAA should develop and certify procedures that take full advantage of ADS-B equipped aircraft in every phase of flight.

- **Build a national platform for ”data link” information exchange.** Voice communication dependent on Very High Frequency (VHF) radio waves is unsafe, slow, and cannot support a significant increase in demand on communication. Eventually replacing this communication infrastructure will permit widespread tactical information distribution and automated routine tasks. Digital data link will also support a safer NAS. The FAA should install the necessary infrastructure to support a digital data link.

The following recommendations can and should be implemented in the less immediate future:

- **Negotiate reciprocal treaties permitting fifth-freedom commercial operations.** The last major anti-competitive airline regulation, surviving the 1978 deregulation, forbids foreign-owned carriers from providing domestic American service. Unilateral deregulation, however, would disadvantage American carriers, who would still be unable to compete in fifth-freedom (i.e., point-to-point within a foreign country) routes. Therefore, US trade representatives should pursue bilateral or multilateral fifth-freedom agreements. The possibility of fifth-freedom flights lifts constraints upon the optimality of commercial operators' transportation networks.

- **Construct new runways where needed.** Adding runways to the nation's most congested airports will increase the capacity in the NAS. Lack of runway space at the most congested airports is a major chokepoint of the hub-and-spoke system.

- **Create a comprehensive V/STOL infrastructure.** Assuming VTOL aircraft are potentially feasible in a commercial airline system, airports should invest in vertiports to increase commuter flights. A vertiport in the vicinity of the main airport would service additional traffic without causing as much stress on the system, due to the vertiport's remoteness from the main runways as well as the nature of VTOL flight capabilities. Airports should also invest in STOL runways whenever possible. Shorter than traditional runways, these runways are less expensive and less detrimental to the environment.

- **Develop distributed decision-making technology and procedures.** Although collaborative decision making currently exists at the most strategic level via ATC command center teleconferencing in response to large-scale changes of NAS constraints, the long-term goal of distributed decision-making will allow tactical responses at the operator level to small-scale constraint changes and thus a highly efficient NAS use. Such decision-making will only be possible with digital avionics and communication networks, and it will require new procedures.

CONCLUSION

Just as flight itself has always fascinated mankind, NAS policy is a subject upon which nearly everyone has strong convictions. Because modern air travel is both a commonplace miracle and a near-universal ordeal, and because a healthy NAS is crucial to the vitality of the entire country, all Americans are stakeholders in the NAS and entitled to their convictions. An explicit formulation of a National Airspace System Policy would serve to form consensus among these varying opinions and establish a common set of purposes and priorities for the NAS. Such a mission statement would help define solutions to major challenges in redesigning the NAS for stability, including contentious questions concerning labor relations, anti-trust regulations, international trade, taxation, and funding priorities for research and development. We recommend that the FAA submit such a statement, soliciting input from all stake-holding groups, including representatives from the military, airlines and cargo carriers, business aviation, general aviation, consumer advocacy groups, and labor organizations.

In investigating NAS sustainability, we are impressed by the quality and quantity of intellect devoted to averting the crisis our country now faces. We are confident that, in accordance with historical patterns of growth, the products of American ingenuity will overcome these national growing pains, themselves indicators of a healthy economy, and produce yet-unforeseen benefits to the nation.

APPENDIX A. TOP 31 HIGH-TRAFFIC AIRPORTS

Thirty-one U.S. airports account for at least one percent of domestic scheduled-service passenger enplanements. The 18 U.S. airlines that account for at least one percent of domestic scheduled-service passenger revenues are required to file performance data under DOT regulation 14 CFR Part 234.

"On-time" operation is defined as occurring up to 15 minutes after scheduled operation. On-time statistics are from June 2004.

Airport		**On-time percentage (%) (Arr/Dept)**
Atlanta: Hartsfield	ATL	64/69
Baltimore/Washington: International	BWI	77/77
Boston: Logan International	BOS	76/81
Charlotte: Douglas	CLT	79/78
Chicago: Midway	MDW	73/73
Chicago: O'Hare	ORD	69/70
Cincinnati: Greater Cincinnati	CVG	78/78
Dallas-Fort Worth: International	DFW	69/69
Denver: International	DEN	76/80
Detroit: Metro Wayne County	DTW	77/77
Ft. Lauderdale: International	FLL	75/83
Houston: George Bush	IAH	65/75
Las Vegas: McCarran International	LAS	72/73
Los Angeles: International	LAX	77/82
Miami: International	MIA	74/74
Minneapolis-St. Paul: International	MSP	77/81
Newark: Liberty International	EWR	72/80
New York: JFK International	JFK	77/80
New York: LaGuardia	LGA	74/82
Orlando: International	MCO	73/79
Philadelphia: International	PHL	71/70
Phoenix: Sky Harbor International	PHX	77/75
Pittsburgh: Greater International	PIT	76/79
Portland: International	PDX	77/85
St. Louis: Lambert	STL	76/81
Salt Lake City: International	SLC	80/86
San Diego: Lindbergh Field	SAN	77/84
San Francisco: International	SFO	75/85
Seattle-Tacoma: International	SEA	74/76
Tampa: Tampa International	TPA	74/80
Washington: Reagan National	DCA	76/84

APPENDIX B. FOREIGN MODERNIZATION PROJECTS

A summary of the top-of-the-line products proven effective to automate air traffic control in Canada and Australia follow. An important facet of the technologies is their modular nature. They are built on common operating systems and are expandable with add-ons or new software. Many of the technologies are similar to U.S. counterparts. However, the technology is more broadly implemented in Canada and Australia with proven efficiency gains.

Canada [89]

- **GAATS:** NAV CANADA's oceanic control at the Gander Area Control Center (ACC), known as Gander Automated Air Traffic System (GAATS), is a good example of ATC automation. Gander ACC handles almost one thousand daily oceanic operations. GAATS includes conflict prediction, conformance monitoring and ADS navigational support, and CPDLC data link. "This automatic composition of the CPDLC uplink responses to clearance requests is essential for efficiency in a busy oceanic environment."[90]

- **CAATS:** NAV CANADA hopes to extend GAATS advancements to the rest of Canadian airspace through the Canadian Automated Air Traffic System (CAATS). CAATS was established in Moncton ACC High Level airspace in 2003. CAATS replaces the previous, 25-year-old flight data processing system. It supports conflict prediction and 4-D conformance monitoring; it integrates flight plan data, airport arrivals and departures, radar data, communications, and flight trajectory. CAATS also automates aircraft handoffs between sectors. It is built on a modular basis to allow future enhancements. NAV CANADA considers CAATS vital to the continued modernization of its air navigation system and plans to expand CAATS to all seven of its ACCs within three years.[91]

- **NADS:** The Northern Airspace Display System (NADS) is a similar, integrated system used in Canada's northern airspace, where radar is not available. It maintains CPDLC, ADS, conformance monitoring, conflict prediction, weather processing, electronic flight strips, and other automated features. The core objective of the system is allowing arbitrary direct routes.

- **EXDS:** Another technology in use in Canada is the Extended Computer Display System (EXDS), part of the Integrated Information Display System (IIDS). The EXDS is in use at 11 control towers in Canada; it allows controllers to manage flight information online in the form of virtual flight strips with a mouse or touchpad.

- **CRDA/VAST:** The Converging Runway Display Aid (CRDA)/Visual Aircraft Spacing Tool (VAST) system is a counterpart to CTAS and was developed by MITRE Corporation, as well. The system supports controller decision-making in the terminal approach area by helping to precisely optimize aircraft spacing. The benefits are especially felt during low visibility and when used with a configuration of runways that cross each other. NAV CANADA estimates that benefits range from 5 percent to 30 percent increase in arrival acceptance rate at various airports and under various weather conditions. The Scheduling and Sequencing System (SASS) is a similar system.

[89] NAV CANADA. NAV CANADA. July 2004. <www.navcanada.ca>.

[90] Gander Automated Air Traffic System eBrochure. xwave. July 2004. <http://www.xwave.com/ebrochures/gaats_frames.htm>.

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Australia

Airservices Australia completed the transition to its modernized air traffic control system in 2000. The system integrates radar, ADS surveillance, and flight plan information, which is displayed for the controller on a single monitor. The flight data usually recorded on flight strips is incorporated into the display and maintained electronically. It also supports CPDLC communication and departure clearance over data link, and air traffic advisories and weather data are distributed electronically. Automated tools support controller decision making by monitoring separation between selected aircraft and projecting future waypoint achievement estimates and conflicts. The controller can edit flight interactively on the display, and he or she can perform routine operations by accessing a list of routine actions for each object on the display. Beyond automated handoffs between centers, the Airservices Australia air traffic control system allows controllers to electronically point to objects on the screen of other controllers remotely.

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APPENDIX D. SCHEDULE OF SUMMER TASK FORCE ACTIVITIES

June 14 - July 9	**Fact-finding Phase**
June 15	FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ (William Benner, Dorothy Buckanin, William Wanner, Ralph Yost, William Vaughan, John Wilkes, Anzel Hassan-Miller, Stan Pszczolkowski, Elizabeth Soltys, Nanette Kalani, Dan McGovern, David Dotsey, Robert Fietkiewicz, Fran DiRocco, Ginger Cairnes, and Frances Makuse)
June 30	jetBlue Operations Center, New York, NY (Al Spain and Chris Collins)
July 7	NASA Headquarters, Washington, DC (Terry Hertz and Robert Pearce) ATCS Command Center, Herndon, VA NBAA office, (Robert Lamond and Jo Damato)
July 8	MITRE-CAASD, McLean, VA (Glenn Roberts, Craig Wanke, Christopher DeSenti, Stephen Welman, Ashley Wymans, Fred Wieland, Thomas Berry, David Moroni, and Keith Campbell)
July 12 - July 23	**Integrative Phase**
July 20	Tower/TRACON facility, Philadelphia International Airport (Adam Grecco)
July 26 - August 20	**Reporting Phase**
August 14	Meeting with John Olcott, President, General Aero Company, Morristown, NJ (at Princeton, NJ)

APPENDIX E. ACRONYM LIST

ADS	Automatic Dependent Surveillance
ADS-B	ADS-Broadcast
AFL-CIO	American Federation of Labor-Congress of Industrial Organizations
ATC	Air Traffic Control
ATCSCC	ATC System Command Center
ATSB	Air Traffic Stabilization Board
CAATS	Canadian Automated Air Traffic Service
CDM	Collaborative Decision Making
CDTI	Cockpit Display of Traffic Information
CPDLC	Controller-Pilot Data Link Communications
CRDA/VAST	Converging Runway Display Aid/Visual Aircraft Spacing Tool
CTAS	Center-TRACON Automation System
DoD	Department of Defense
DOT	Department of Transportation
EXDS	Extended Computer Display System
FAA	Federal Aviation Administration
FAST	Final Approach Spacing Tool
FFP1	Free Flight Phase 1
GA	General Aviation
GAATS	Gander Automated Air Traffic System
GAO	Government Accountability Office
GDP	Ground Delay Procedure
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IIDS	Integrated Info Display System
IMC	Instrument Meteorological Conditions
LAAS	Local Area Augmentation System
MIT	Miles in Trail
Mode S	Mode Select
NADS	Northern Airspace Display System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controller Association
NBAA	National Business Aviation Administration
OEP	Operational Evolution Plan
PATCO	Professional Air Traffic Controller's Organization
pFAST	passive FAST
RJ	Regional Jet
RNAV	Area Navigation
RNP	Required Navigation Performance
RVSM	Reduced Vertical Separation Minima
SASS	Scheduling and Sequencing System
SNI	Simultaneous Non-Interfering
SWAP	Severe Weather Avoidance Procedure
TCAS	Traffic Alert and Collision Avoidance System
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
VDL-3	Very High Frequency Digital Link Mode 3
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	Very High Frequency Omnidirectional Range
VORTAC	Very High Frequency Omni-Directional Radio Range and Tactical Aid to Navigation beacon
V/STOL	Vertical/Short Takeoff and Landing
WAAS	Wide Area Augmentation System

Airport Acronyms

DCA	Ronald Reagan Washington National Airport
DFW	Dallas/Ft. Worth International Airport
EWR	Newark International Airport
JFK	John F. Kennedy International Airport
LGA	New York LaGuardia International Airport
ORD	Chicago O'Hare International Airport
SFO	San Francisco International
SMF	Sacramento Metropolitan Airport