JOURNAL OF AIRCRAFT
Vol. 41, No. 1, January–February 2004

Next Century Aerospace Traffic Management: The Sky is No Longer the Limit

Jim Cistone*
Lockheed Martin Corporation, Rockville, Maryland 20850

About 100 years ago, on 17 December 1903, Wilbur and Orville Wright first flew the Wright Flyer and so began the first century of powered flight. Unfortunately, no one thought to invent an airspace management system to manage all of the aircraft flights that ensued from the Wright's invention! As new aircraft were designed, improved, and built, the need soon arose to have some kind of order, management, and direction in how these aircraft were operated in the air and on the ground. Thus began the air traffic control system, born out of necessity, and evolving through reactions to aviation incidents and events. The paradigm of air traffic management has never changed: the safe, expeditious flow of air traffic through the airspace. The evolution of aviation over the past 100 years has been phenomenal, but much of the air traffic management vision took place over 50 years ago. As we enter the next century of flight, we see a vision for aeronautics that is even more spectacular than the changes we experienced during the first century: aircraft that can change shape, heal themselves, and fly (maneuver) like a bird as well as personal air vehicles allowing people to fly "door-to-door." Such remarkable advances in vehicle technology will completely change the air traffic management problem. Highways in the sky are already congested, and the significant addition of air vehicles with the envisioned operating characteristics will create a very complex airspace volume. Although there is surely enough air space to use, air traffic will require significant management to maintain safety, security, order, and efficiency that will provide enough flexibility to allow people and goods to be moved at will. We now have the opportunity to utilize technology to fix the airspace management system of today providing adequate capacity to meet demand during the early part of this century. Moreover, we have the opportunity to set the stage for the aerospace management system of the future that will keep safety, security, capacity, and efficiency paramount and allow the growth of aviation to continue unimpeded. Now is the time for the United States to set the course for the future of aeronautics and continue to maintain world leadership in aeronautics. The sky is no longer the limit.

Introduction: The Beginning

IN just 12 s, at 1035 hrs, on 17 December 1903, Orville and Wilbur Wright entered the annals of history with their first flight at Kitty Hawk, North Carolina (Fig. 1).

In this first century we went from the first flight in a single powered aircraft of 120 ft (36.6 m) in 12 s carrying one passenger to a fleet of over 200,000 U.S. based aircraft. Today, some aircraft can carry over 500 passengers, have wings pans and length approximately twice as long as the first flight, have speeds more than 200 times greater than the speed of the Wright Flyer's first flight, and nonstop flights that circle the globe. In addition, we went from four flight operations (and our first crash) in 1903 to more than 100 million flight operations per year in the United States today.

Table 1 depicts other examples of how far we have advanced in just one century of powered flight.

Progress over the past century has also changed the world in different ways. There was no media coverage of the first flight in 1903, but today it would have garnered worldwide prime-time television coverage. None of the airspace management problems we have experienced as a result of this rapid growth existed back in 1903. Most of all, in 1903 the future of aviation was limited to the imagination, and airspace management evolved as more aircraft were developed. Today, we have the ability to project the current state of aviation into the near future, but the next generation of aviation is on the horizon, and we have the opportunity to prepare for the advent of the next century of aviation.

Airspace Management

Historical Perspective

Table 2 presents several key milestones in the history of airspace management.

After the Wright brothers first flight in December 1903, aviation vehicle technology progressed quite rapidly. Other adventurers and engineers were eager to test their ability at inventing a flying machine. It is fair to say that no one in 1903 envisioned derivatives of these flying machines carrying people around the world or packages for overnight delivery. However, by the next decade the value of these flying contraptions began to emerge. How strange that all of this research, invention, and progress in aviation was made without an extensive business case.

During the first two decades of flight, there were so few aircraft that a need for airspace management was not evident. Most of the activity concentrated on building newer and better vehicles, although the introduction of airmail began to drive aviation growth. One of the first events to recognize a need for management of airspace took place in Europe. As aircraft flew in Europe, they raised the issue of traversing national boundaries. In 1919 the International Commission for Air Navigation (ICAN) was created to develop general rules for air traffic, although the United States did not sign the ICAN Convention. Back in the United States airmail was the focus in the third decade of aviation. In 1925 President Calvin Coolidge appointed a board to recommend a national aviation policy. Dwight Morrow, a senior partner in J.P. Morgan's bank and later the father-in-law of Charles Lindbergh, was named chairman. The board submitted its report to President Coolidge in 1925, and its key recommendation was that the government should set standards for civil aviation outside of the military. The result of the Morrow Report was the Air Commerce Act of 1926. This legislation authorized the Department

Received 10 April 2003; revision received 24 June 2003; accepted for publication 26 June 2003; presented as Paper 2003-2792 at the International Air and Space Symposium and Exposition The Next 100 Years, Dayton, Ohio, 16 July 2003. Copyright © 2003 by The Lockheed Martin Corporation. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission. Copies of this paper may be made for personal or internal use, on condition that the copier pay the $10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0021-8669/04 $10.00 in correspondence with the CCC.

*Senior Program Manager, Transportation and Security Solutions, 9211 Corporate Boulevard, 870/3A27; jim.cistone@lmco.com. Associate Fellow AIAA.

Table 1 Examples of aviation progress during the 1st century of powered flight

Characteristic	1903	Today
PAX per aircraft	1 (pilot)	500^{+}
Number of U.S. aircraft	1	$200{,}000^{+}$
Flight operations	4	100^{+} million
Number of pilots	2	$600{,}000^{+}$
Longest nonstop distance flown	852 ft	Around the world
Instrument operations	0	∼70 million
Unruly passengers	0	∼300
Event media coverage	None	Worldwide
Morphing wings	Yes	Experimental

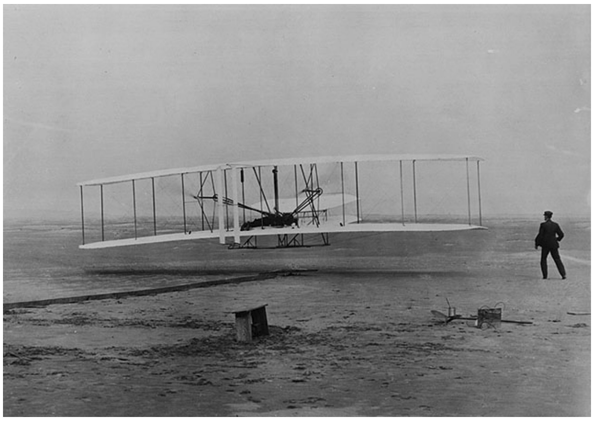

Fig. 1 17 December 1903 at 1035 hrs [Credit: Library of Congress, Prints and Photographs Division, reproduction number, e.g., (LC-DIG-ppprs-00513)].

of Commerce to establish air traffic rules for the navigation, protection, and identification of aircraft, including rules as to safe altitudes of flight and rules for the prevention of collisions between vessels and aircraft.

This was the beginning of air traffic control as we know it and the first of several boards or commissions to make airspace management recommendations. In May 1927 Charles A. Lindbergh made his historic flight from New York to Paris, and this event thrust aviation into the worldwide limelight. Aviation was beginning to gain respect in both civilian and military domains, and national aviation growth was the result.

As traffic increased, some airport operators realized that the existing general rules of the air were not enough to prevent collisions. They began to provide a form of control based on visual signals. The early controllers stood on the field waving flags to communicate with pilots. Archie League was one of the system's first flagmen, beginning in 1929 at the airfield in St. Louis, Missouri.

The fourth decade of powered aviation showed remarkable progress and growth. Early in the decade, radio became widely used in aviation management. Gradually, the airport flagmen were replaced by control towers, and radio formed the basis of communication between ground and aircraft. By 1932 almost all airline aircraft were being equipped for radio–telephone communication, and about 20 radio control towers were operating by 1935.

Further increases in flights created a greater need for management beyond airports, extending out along the airways. In 1935 the principal airlines using the Chicago, Cleveland, and Newark airports agreed to coordinate the handling of airline traffic between those cities. In December 1935 the first airway traffic control center opened at Newark, New Jersey. Additional centers at Chicago and Cleveland followed in 1936.

In response to an airline crash in 1935, Congress commissioned a report on aviation safety. As a result of the Copeland Committee Report, the Civil Aeronautics Act of 1938 was enacted. The Civil Aeronautics Act transferred the federal civil aviation responsibilities from the Commerce Department to a new independent agency, the Civil Aeronautics Authority (CAA). The legislation also expanded

Table 2 Airspace management milestones

Year	Event
	First decade: 1900–1909
1903	Wright brothers first flight
1908	First American airplane passenger and the first passenger fatality
	Second decade: 1910–1919
1914	First scheduled air service: St. Petersburg–Tampa Air Boat Line
1918	First regularly scheduled airmail service begins
1919	International commission for Air Navigation created to develop general rules for air traffic
	Third decade: 1920–1929
1925	Airmail Act of 1925—“Kelly Act”
1925	Morrow Report—recommended a national aviation policy
1926	Air Commerce Act
1927	Lindbergh Crosses the Atlantic
1927	Federal Airways Systems begins
1929	First air traffic controller: Archie League, St. Louis
	Fourth decade: 1930–1939
1930	Two-way radio communication begins
1932	First airport control tower at cleveland
1934	Bureau of Air Commerce established by U.S. Congress
1935	First air traffic control unit established by airlines at Newark, NJ
1935	Radio Technical Commission for Aeronautics (RTCA) established
1936	Copeland Committee Report
1936	Instrument Flight Rules (IFR) established
1938	Civil Aeronautics Act of 1938 creates Civil Aeronautics Authority (CAA)
	Fifth decade: 1940–1949
1940	CAA reorganization to Civil Aeronautics Board (CAB, authority, and Safety) and Civil Aviation Administration
1941	Air Traffic Control (ATC) Division established, 23 ATCCs, 100% Civil ATC, controlled and uncontrolled airspace
1941	Interdepartmental Air Traffic Control Board
1942	CAA established Interstate Airway Communication Stations [Flight Service Station (FSS) of today]
1945	Air Coordinating Committee and Preliminary International Civil Aviation Organization
1946	Decca Navigation System (DNS) first demonstrated Area Navigation (RNAV)
1947	International Civil Aviation Organization (ICAO) established
1947	RTCA Task Force, Special Committee 31 Recommendations for ATC modernization
1948	Beginnings of delays (weather in New York city causes 100-mile ripple delay)
	Sixth decade: 1950–1959
1954	September 15, “Black Wednesday”: IMC on East Coast causes major delays
1954	SC-31 modernization only 47% complete because of budget restrictions, ECD 2014!
1956	First Air Route Surveillance Radar (ARSR)
1956	Grand Canyon midair crash
1957	Airways modernization Board (AMB) established for research and design
1957	Positive Control Airspace above 24,000 ft
1957	Curtiss Study Recommendation: AMB designs common ATC system, establishes Federal Aviation Administration (FAA)
1958	Entry of Boeing 707 jet aircraft into airline service
1958	National Aviation Facilities Experimental Center (NAFEC)
1958	Federal Aviation Agency established
	Seventh decade: 1960–1969
1961	President John F. Kennedy orders “Project Beacon,” proactive National Aerospace System (NAS) modernization plan
1962	Project Beacon Report: Develop Flight Data Processing (FDP), Radar Data Processing (RDP) and display equipment
1964	American Airlines introduces SABRE
1967	U.S. Department of Transportation (DOT): FAA, National Transportation Safety Board (NTSB), CAB
1969	RNAV routes established
1969	First wide-body jet, Boeing 747, introduced into airline service
	Eighth decade: 1970–1979
1970	FAA establishes Central Flow Control Facility
1973	FAA begins computer processing of flight plans nationwide
1978	Airline deregulation
	Ninth decade: 1980–1989
1981	Professional Air Traffic Controller's Union (PATCO) strike
1982	NAS plan (Brown Book) unveiled

(Continued)

Table 2 Airspace management milestones (continued)

Year	Event
1984	CAB sunset Act transfers remaining functions of CAB to DOT
	Tenth decade: 1990–2000
1991	Capital Investment Plan (CIP) replaces NAS plan
1994	RTCA Task Force 3, recommendations for “Free Flight”
	Next Century: 2001–2010
2001	September 11- National Airspace system shut down because of terrorist strike

the government’s role by giving the CAA the power to regulate airline fares and to determine the routes that air carriers would serve.

This decade of aviation saw the rapid growth of the airlines and corresponding growth in airliners produced by Boeing, Douglas, and others. For example, Douglas produced the DC-3, often called the plane that changed the world. The DC-3 was the first aircraft to enable airlines to discover profits while carrying passengers. As a result, it quickly became the dominant aircraft in the United States, following its debut in 1936 with American Airlines. The DC-3 had 21 seats and was considered a safer plane than many predecessors because it was built of an aluminum alloy stronger than materials previously used in aircraft. Furthermore, it had more powerful engines (1000 h vs 710 h for the DC-2), and it could travel coast to coast in only 16 hours—a fast trip for that time.

The fifth decade of aviation began with reorganization. In 1940 President Franklin Roosevelt split the Civil Aviation Authority into two agencies: the Civil Aeronautics Administration (CAA) and the Civil Aeronautics Board (CAB). CAA was responsible for air traffic control, airman and aircraft certification, safety enforcement, and airway development. CAB was entrusted with safety rulemaking, accident investigation, and economic regulation of the airlines. Both organizations were part of the U.S. Department of Commerce. Unlike CAA, however, CAB functioned independently of the Secretary.

In 1941 the CAA began construction and operation of air traffic control (ATC) towers, which grew to 115 by 1944. In the postwar era ATC at most airports was eventually to become a permanent federal responsibility. Because of the tension between the military and civil agencies for control of air traffic, an Interdepartmental Air Traffic Control Board was constructed in 1941to coordinate activities between government agencies. The Air Coordinating Committee (ACC), which was chartered to make technical, economic, and industrial recommendations on aviation, absorbed this board later.

The postwar years saw the beginning of a revolutionary development in ATC, namely, the introduction of radar. Now, controllers could see aircraft on their radarscopes, and radar was used for flight following, separation, and traffic management.

By the postwar years aviation was a large industry. Worldwide attention to aviation was shown by the formation of the International Civil Aviation Organization (ICAO) in 1947. ICAO was formed to coordinate the growth of aviation and to attempt to develop standards for aviation around the world.

In 1947 the ACC requested that the Radio Technical Commission for Aeronautics (RTCA) form a task force to attempt to predict the future needs of the nation’s air traffic control system. This action was initiated by the ACC as a review of a paper prepared by the Air Transport Association (ATA), entitled “Recommendations for the Safe Control of Expanding Air Traffic.” RTCA formed Special Committee 31 (SC-31) to perform this task, and SC-31 delivered its final report “Air Traffic Control” in 1948. It is noteworthy, in view of subsequent history, to list the findings of the SC-31 report. The report[1] called for nine basic types of equipment:

1) The first element was an airborne transponder that would reply to ground-based interrogations and a discrete address air-ground communications link (private line) now called the data link.

2) Airborne navigation equipment was needed to provide all weather navigation information through all phases of flight, including the airport surface. It was also intended to be the receiving link for the aircraft situation display. This display was to display to the pilot in the cockpit the position of altitude layers, obstacles to flight, aircraft occupying each altitude layer, specific and hazardous weather conditions, along with its own position. Near the situation display in the cockpit would be a symbolic display, showing clearances received from air traffic control via the private line.

3) Ground-based traffic data relay equipment was needed to relay information between aircraft and the automatic air traffic control equipment (see number 4) by the private line and secondary radar systems.

4) Automatic air traffic control equipment was also needed, including airspace separation, flow control with both symbolic and pictorial flow control displays, flight-path planning, airport time utilization, and a display for general planning, which would allow an operator to pick a route that could be followed without delay during a specific period of time.

5) Ground-based navigation equipment was necessary to provide information for aircraft navigation enroute (on and off airways), during holding, and on initial approach to land. Included with this equipment was the transmitting equipment to provide a situation display of the area to the aircraft, as well as air–ground aural communications.

6) Ground-based navigation equipment was necessary to provide approach and landing information to the aircraft and to allow the controller to monitor the aircraft’s approach.

7) Navigation equipment was needed to provide airport surface navigation information for taxiing aircraft and ground vehicles.

8) To allow air traffic control to monitor and control the flow of aircraft within the airport area, SC-31 called for airport utilization, planning, and control equipment. This equipment would have a pictorial display of the current position of aircraft in flight and all aircraft and vehicles on the ground. A symbolic display would show both present and future position of aircraft, detailed information for aircraft operating in the airport area, and the current rate of aircraft flow in that area.

9) The ninth element of the SC-31 report was to provide intercommunications between traffic control units, weather offices, and airline operations offices. Media included aural communications, point-to-point communications in Morse code, and microwave and/or coaxial cable point-to-point relay circuits.

Finally, SC-31 called for the development of an air traffic control simulator to provide a means for proving the efficiency of the equipment components of the basic system by simulating traffic control problems using control inputs and outputs as they would occur in actual usage.[1] The simulator was also intended for training air traffic control personnel in the use of new procedures and equipment.

The ACC unanimously accepted the RTCA report as a guide to the further development of our airways system. In January 1950 President Harry S Truman presented the 1948 Collier Trophy to RTCA for the establishment of a guide plan for the development and implementation of a system of air navigation and traffic control to facilitate safe and unlimited aircraft operations under all weather conditions.

Finally, during the late 1940s delay began to accompany poor weather conditions. This was merely an indication of things to come!

During the sixth decade of powered aviation, in the 1950s air traffic control suffered. Delays under instrument meteorological conditions (IMC) increased, and budget cuts for aviation became routine. In 1954 one year after the initial target completion date for SC-31’s recommendations, the estimate to complete the system was in the year 2014! As it stands in 2003, the 2014 date would be difficult to achieve.

A midair collision over the Grand Canyon caused yet another study, and in 1957 the Curtiss Report was issued. This report recommended that the Airways Modernization Board (AMB) was to design a common air traffic control system that would serve the needs of both civil and military aviation. Further, the Curtiss Report recommended the formation of a new agency to absorb the functions of the CAA and AMB, and in 1958 the Federal Aviation Agency was born.

In 1960 a terrible midair collision between a United Airlines DC-8 and a TWA Constellation happened over New York City. President Kennedy issued an order in 1961 for the FAA to conduct a scientific and engineering assessment of our aviation and air traffic control system and to prepare a long-range plan to ensure safe and efficient traffic control within the United States. This was called "Project Beacon," and the report issued in 1962 called for modernization of radars, use of secondary radars and transponders, as well as the installation of computer-processing equipment at air traffic control facilities. First of the computerized systems was a flight data-processing system to aid the controllers in processing and communicating flight plan information. Second was a radar data-processing capability to show aircraft tracks, identity, altitude, and speed.

With the advent of the jet age and availability of computers, airlines also were automating their environments. American Airlines introduced their SABRE system for airline reservations during this decade. Finally, as the government became more involved with transportation, a Cabinet-level Department of Transportation (DOT) was created, and the FAA and CAB were merged into the DOT. In addition, the National Transportation Safety Board (NTSB) was created to investigate and determine the cause of transportation accidents.

Finally, the end of the 1960s saw the development of area navigation (RNAV) routes, which allowed direct point-to-point flights. In addition, the introduction of the first jumbo jet, the Boeing 747, occurred in 1969.

Traffic continued to grow in the 1970s. The FAA established a Central Flow Control Facility in 1970 to prevent clusters of congestion from disrupting the nationwide air traffic flow. In addition, nationwide processing of flight plans was operational in 1973. The final act of the 1970 decade would cause a major impact to air traffic management and control for decades to come. Airline deregulation was enacted in 1978. With this act the airlines were free to determine their own route structures as well as fares for their routes. The economics of deregulation moved airlines into a hub-and-spoke operation, where airlines fly from points (spokes) to a central hub, exchange passengers and freight, then fly from the hub to outlying points. Thus, a passenger gets from point A to point B by going through a hub somewhere in the middle of A and B instead of flying directly from A to B.

The decade of the 1980s started with another first. In 1981 the Professional Air Traffic Controller's Union (PATCO) staged an illegal strike. Two days after the strike, when the controllers refused a Presidential Order to return to work the FAA terminated all striking controllers. This action threw the National Airspace System (NAS) into chaos, although the resulting flow management system, essentially a reservation-based system, significantly reduced the volume of flight operations. In addition, most operating flights were able to adhere to their reservation or slot, and that at least provided some predictability in the NAS operation.

In January 1982 the FAA unveiled their new NAS Plan. The plan called for modernized flight service stations, more advanced systems for ATC, and improvements in ground-to-air surveillance and communication. Better computers and software would be developed, air route traffic control centers would be consolidated, and the number of flight service stations was to be reduced.

In 1988 the FAA embarked upon a monumental modernization program called the Advanced Automation System (AAS). This program was intended to modernize the entire National Airspace System, eventually with automated air traffic control. Unfortunately, the AAS program schedule slipped out several years, and the AAS program was curtailed in the mid-1990s.

During the last decade of powered flight, the Capital Investment Plan (CIP) replaced the NAS Plan. The ghost of RTCA SC-31 returned in 1994 when RTCA established a task force to investigate Free Flight, a look into the future where we can fly without restriction. A Free Flight implementation plan has been established, and limited elements of Free Flight are slowly becoming operational.

Current State of Affairs—2003

The management of the National Airspace System (NAS) remains largely as it was during the past several decades. Most of the vintage 1960s hardware has been replaced in the ATC facilities, but the control of air traffic continues to be based upon human performance. NASA and the FAA continue research into elements of automation intended to increase NAS capacity, but the transition from research to operation is slow, sometimes 10 to 20 years. Airspace and airport gridlock occurs in the presence of inclement weather, even when the extent of the weather constraints are localized. The outlook for the near future is Free Flight, but full-scale implementation is decades away, as much of the critical research is under funded at this time. The FAA has developed the Operational Evolution Plan (OEP) to focus upon NAS modernization efforts that contribute to capacity increases. This plan represents a 10-year rolling window, but many believe that NAS demand will continue to increase at a greater rate than NAS capacity as provided by the OEP. Recently, the FAA has begun a review of the OEP with the intent of accelerating the implementation of capacity increasing initiatives, as well as adding new initiatives aimed at capacity growth. These actions will certainly help increase NAS capacity at a faster rate, but it is still unclear whether these initiatives are enough. In addition, the FAA has initiated a Joint Program Office (JPO) to develop the transformation of NAS toward the year 2025. The creation of this JPO resulted from recommendations by the President's Commission on the Future of Aerospace and calls for action from many organizations including AIAA. The JPO will coordinate research and development across many Governmental organizations, including the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), the Department of Homeland Security (DHS), and the Department of Commerce (DOC), and is chartered with developing a plan for the transformation of NAS. The NAS transformation plan is due for publication later in 2003.

On 11 September 2001, terrorists, in an attack against the American people, utilized the U.S. National Airspace System as a weapon of mass destruction. Several commercial airliners were hijacked and used as airborne missiles directed at national civilian and military targets in an attempt to disrupt life in America. The economic impact upon the aviation industry has devastated the precarious financial position of most airlines, and many have declared bankruptcy. Travel demand has dropped and is not expected to resume to 2000 levels until 2005 or later. This attack was a tragic use of aviation, one of our greatest national resources.

There is little doubt that aviation is critical to the world economy and to our modern way of life. 11 September 2001 was a tragic lesson in the importance of air commerce, as we all felt the impact of its temporary loss. Aviation growth now has a brief reprieve in the battle for National Airspace System capacity, and we need to take some definitive action now to bring capacity ahead of future demand.

To a large extent, air traffic control and airspace management have evolved through reaction to changes in aircraft technology and the growth of air commerce. Predicaments in aviation have generally resulted in commissions, studies, and plans, but implementation of recommendations appears evasive. The vision of RTCA SC-31 is still not realized 55 years later, and along the current implementation path, many aspects of this vision continue as visions.

The behavior of the National Airspace System is very complex. During the year 2000, NAS was near gridlock at times when demand, capacity, and weather constraints interacted in a complex manner to create excessive delay for air travel. The delay, however, is only a manifestation of the problems within NAS, and the first step of the next century of aviation should be to obtain a thorough understanding of the NAS, the nature of the demand, and the causes of NAS delay, unpredictability, and inflexibility. Until the root causes are well understood, there is little hope of achieving an optimum NAS operation. There is also the danger that these root causes, if not understood and contained, will be carried over into the modernized version of NAS.

Next 100 Years—New Century for Aviation

We have traveled so far in this last century that it is difficult to envision where the next century will take us. In fact, Charles A. Lindbergh stated in an interview[2] with *Popular Mechanics* in 1927:

> Of course, no one can accurately forecast the final effect of aviation upon the world. We can go ahead a few years and show the general trend beyond that, but no one can tell just how far flying will take us.

He continued to state:

> The next generation will be born without a fear of the air, because the airplane will be accepted just as the automobile is today. The United States will pull ahead of other nations because of its favorable geographic situation. By that, I mean the long distances between important business centers, and the good flying country intervening. Also, the high value Americans place on their time will help, as will our efficient production methods.

Lindbergh was correct for most of the first century, but the world is beginning to pass the United States in aviation technology.

Near-Term Future

During the next few years, we must develop a plan to modernize the National Airspace System and to correct the root causes of delay. It appears that moving toward the Free Flight vision will provide us with the needed capacity as well as more predictability, efficiency, and flexibility in NAS operations. Our vision should be one of creating a NAS that is optimum for all users. Unfortunately, optimum is difficult to define and can be quite elusive. Some examples of optimum include the following:

1) The first is recreational flight. During a weekend flight, a recreational pilot might view optimum as a segment of airspace free from other traffic and hazards, where he can perform sightseeing on a Sunday afternoon.

2) General aviation/business is the second example. A general aviation pilot flying his single-engine aircraft on a business trip might view optimum as a direct, straight-lined route from his departure point to his destination at the desired time of the day. This route would be free of traffic, weather, and other airborne conflicts.

3) The third example is general aviation fleet operator. A large general aviation operator responsible for a fleet of aircraft can view optimum differently. The operator's mission is to transport a large number of people and/or cargo under constraints of desired schedules, the state of the aircraft fleet and flight and maintenance crews, as well as fleet maintenance and financial resources. Optimum, in his view, is to meet all of the demands and requirements of his customers at minimum cost and with the least disruption of his assets. This view of optimum has elements that reach far beyond the traditional realm of air traffic control, but every element has an effect upon the airspace system. When the operator achieves a plan for the day, he then expects the airspace system to allow execution of the plan with minimum perturbations.

4) Airline operations is the fourth example. An airline's view of optimum is even more complex, and there is considerable variation between individual airlines. In general, an airline's objective is to fly their schedule on time. Airline schedules are market driven, and an element of airline optimization is to create a schedule that serves their market and makes optimum use of their aircraft, personnel, and maintenance resources. Given the size and geographical extent of the airline, flying on schedule involves widespread planning and coordination far beyond the scope of air traffic control. Once the airline's plan is finalized, its demand upon air traffic control is to allow unimpeded execution of the plan.

The preceding-simplified examples possess a common thread:

1) The aircraft operator must have the ability to develop a plan for the flight or flights.

2) The air traffic service provider must have the ability to accept the plans from all users and to coordinate the various demands with available airspace system resources.

3) The flight crew must have the ability to execute their individual flight plan.

4) All parties must have the ability to continue close coordination such that any plan interruptions can be accommodated with the least impact to the overall National Airspace System.

From a systems perspective the Free Flight airspace management system that accommodates the self-optimization of flights will have a driving requirement to allow tens of thousands of disparate initial views of optimum and tens of thousands of real-time optimum change requests. The challenge for system designers and developers will be to discover the key to unlock system flexibility, and this key will be based upon information sharing, collaboration and management.

This next generation airspace system will represent a quantum leap from the present state of air traffic control and a significant departure from aviation heritage. Concepts for this vintage of NAS are being developed at present, and the design and development of system components must be accelerated from the historical pace if capacity is to overtake (and stay ahead of) demand.

Far-Term Future

Aviation continues to play a key role in world economics. In fact, the economy and aviation are tightly coupled. Therefore, it is likely that aviation will continue its eminence for the next century, much as railroads were coupled to the economy in the 19th century. However, it is possible that aviation could follow the railroads into a subordinate role in future transportation, but there would need to be an aviation replacement, as aviation was for the railroads. The most likely replacement for aviation in its entirety is teleportation: beaming people and goods around the world and into other worlds. However, the technology for teleportation is not likely to be developed within the time frame of the next century.

The remaining possibility is that aviation will change from our current situation to some different form. It is these new forms that will place new demands upon the airspace and consequently will have the potential to change airspace management from its present or near term form to some totally different concept.

One class of vehicle that exists today is the unmanned aerial vehicle (UAV) or remotely piloted vehicle. These vehicles have flight characteristics similar to conventional aircraft, and there are visions that these unmanned vehicles could be used extensively for cargo transport. Some visions have UAV launching ports located in industrial park areas, where they would be loaded with cargo and catapult-launched into flight. As they reach their destination, they would land in a similar environment and their roll would be arrested in a short distance. People might find the aircraft dynamics intolerable, but cargo does not mind. Today's UAVs are small sized, but those of tomorrow could be large enough to carry substantial volumes of cargo. Thousands of these vehicles injected into the NAS traffic stream would certainly change the paradigm for NAS management. Air cargo shipment today utilizes large ground-based sortation facilities, such as Federal Express has in Memphis. However, to achieve faster deliveries a large flying sortation ship could be placed in an airborne orbit. UAVs could dock with the ship, deposit their cargo, and receive new cargo for delivery, all in near real time. The flying sortation center would orbit in an optimum manner, providing the best pattern to match the desired cargo distribution. Again, the airspace management paradigm would change drastically.

Another interesting change in vehicle technology is associated with aircraft that have morphing structures. Interestingly, the Wright Flyer had morphing wings, but the modern technology version uses nanotechnology. Figure 2 illustrates NASA's current concept of a morphing airplane.

Imagine an aircraft that can self-heal and that could change wing shape as appropriate to the phase of flight. One can compare a flock of birds on a lake suddenly taking off in flight, as shown in Fig. 3, to future morphing aircraft. Thousands lift off within a few feet, retract their landing feet, and go to cruise configuration all while flying in formation and without collisions.

Morphing-wing aircraft offer the same possibilities, and although we may not have the occasion to see thousands of morphing planes take off in formation the possibility exists for aircraft to utilize a minimum amount of runway for take off and departure. This feature would allow the use of smaller runway areas or more aircraft operations simultaneously on a single runway. Whereas we see the possibilities with tilt-rotor aircraft today, the cruise configuration of morphed aircraft could be made optimum for the load and the flight. Such technology is far from finalization in 2003, but nanotechnology is a promising area subject to intense research, and there are already commercial applications including no-wrinkle pants and tennis ball liners. Airport undercapacity would be a thing of the past, and nanoplanes could utilize inner-city resources as well as

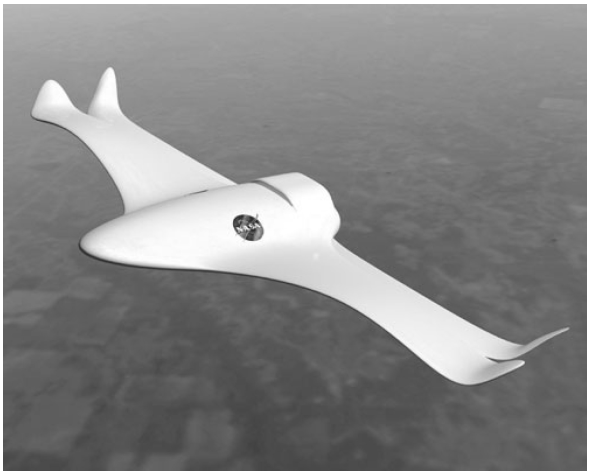

Fig. 2 NASA concept for a morphing aircraft. (Credit: NASA Picture Exchange Gallery).

Fig. 3 Thousands of birds in take off configuration without collision. (Credit: Lockheed Martin Digital Photo Collection).

existing airfields for operation. Clearly, the arrival and departure performance characteristics and the cruise regime operation would change airspace management considerably. The aspect of formation flights also enhances capacity. Formations of flights could fly across the country, with aircraft peeling off to their destination or joining the formation as required. Today, experimentation with small microplanes is underway.

Imagine, as shown in Fig. 4, the civil applications of a small micropackage delivery device that could transport packages to and from the mother ship in orbit, from one building to the mother ship and back to another delivery address. In fact, the small microcraft might be capable of delivering from one door to another. They might never beat the business case of email and fax for letters and documents, but for parcels and small packages they could achieve a new look for cargo aviation. Of course, the navigation, control, and management of the airspace under these conditions would seem nightmarish to us now; however, airspace management technology must move forward also.

Next we have the Jetson's personal air vehicles (PAVs), one in every garage/hangar. People would use these vehicles much as we use automobiles today. NASA has depicted a vehicle in their Blueprint for Aviation (data available online at http://www.aerospace.nasa.gov/aero_blueprint/index.html), and it is shown in Fig. 5.

Although it might seem like another nightmare, having today's aggressive drivers (or their heirs) airborne instead of ground-based, we also must conclude that some automatic pilot assistance would

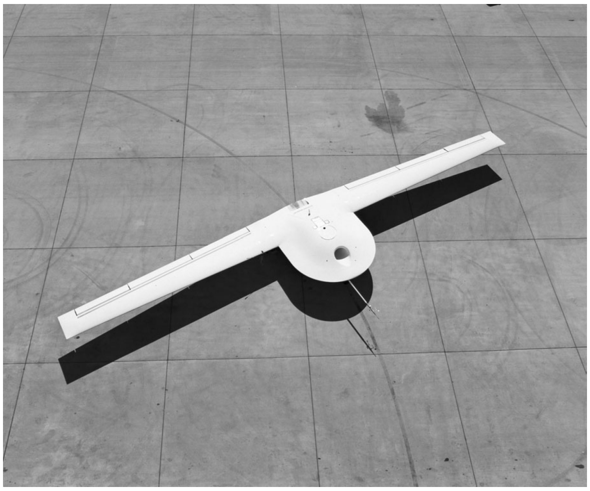

Fig. 4 Micro-UAV delivering a package in your driveway. (Credit: Lockheed Martin Digital Photo Collection).

Fig. 5 NASA's vision of a personal air vehicle. (Credit: NASA Aeronautics Blueprint).

be available to navigate and manage the trajectories of the PAVs. Although these vehicles can traverse all altitudes in the National Airspace System, one would expect the lower altitudes to be more populated with such aircraft. Again, the airspace management problem appears intractable with today's technology, but airspace management technology will advance as well.

This leads us to space. Today space launches and recoveries block off airspace during the respective operations. This does not present a major capacity constraint given the frequency of space operations, but the growth of space launches and recoveries could ultimately pose a constraint upon airborne atmospheric traffic. Again, the current paradigm for airspace management would require change.

Conclusions

We have seen the development of our National Airspace System move in response to aircraft development, accidents, and incidents. Many commissions and boards have been formed to study the problem, and many reports have been written. The RTCA SC-31 report, written 55 years ago, was especially visionary. Today, much of that vision remains undeveloped. The promise of Free Flight, which resulted from another RTCA visionary task force gives hope for a more efficient operation of the NAS, with the possibility of approaching optimum for all classes of NAS stakeholders. The development of Free Flight is also moving at a slow pace, and while we have a reprieve because of the tragedy of 11 September 2001 increased traffic demand is predicted to return by 2005. Given the long lead times to turn research into operation, we probably will not be ready to meet the NAS demand in 2005, unless we act quickly and decisively now to develop and execute a plan of action to improve NAS operation in the next few years. This action must be followed by a longer-range NAS modernization effort to set the stage for the next century of aviation operations.

The act of closing the National Airspace System on 11 September 2001 was prudent, given the uncertainty of the scope of the national threat. However, future designs of the NAS must have security requirements that will help identify such threats and allow sharing of information with appropriate authorities to permit them to neutralize any threat within the smallest possible impact area. To allow such terrorist attacks to cripple our National Airspace System and deal a sharp blow to aviation's economic well being is to give the terrorists the victory that they desire.

Air traffic control has evolved and reacted to the injection of new vehicles into NAS, accidents, and incidents. The future of vehicle technology shows promise for several new and revolutionary classes of vehicles. Because aviation is so critically tied to our lives, we no longer have the luxury of allowing NAS modernization to evolve behind vehicle technology evolution. We must prepare now to define a NAS management system that will accommodate the near-term demands of the next few years, will allow for flight optimization for all stakeholders in the next 10–20 years, and furthermore, will also set the stage for future air vehicle developments allowing appropriate technology to be quickly inserted such that NAS is available to manage these new vehicle classes. There is simply no time to continue NAS development in a reactionary mode. Failure to keep NAS capacity ahead of the demand curve will throttle back the growth of aviation and consequently, the economy.

People might laugh and doubt that these crazy new flying contraptions will ever move from cartoon to reality. However, few took notice of the events of 17 December 1903. People laughed at those crazy men in their flying machines, but within a decade of that cold, windy day in North Carolina people began to realize that aviation was here to stay. Today, aviation is pervasive in our lives, our security, and our economy. The next century of aviation promises even more magnificent advances in technology than we saw in the last century, but we must have an airspace management system that can provide the capacity to meet demand, which can operate efficiently, flexibly, and predictably enough to allow self-optimization for airspace users and most importantly a NAS that can form the basis for evolution into the next century of advanced aviation technology. Now is the time to create a National Airspace System for the next century.

During the first century of aviation, the sky was the limit. During the next century of aviation, the sky is no longer the limit.

References

[1]Osmun, William G., *The Authority of Agreement, A History of RTCA*, RTCA, Washington, DC, 1985.

[2]"Lindbergh Tells Future of Aviation," Republished from the Popular Mechanics, Nov. 1927, URL:http://www.popularmechanics.com.

Editor-in-Chief: Lyle N. Long, Pennsylvania State University

AIAA is launching a new professional journal, the *Journal of Aerospace Computing, Information, and Communication,* to help you keep pace with the remarkable rate of change taking place in aerospace. And it's available in an Internet-based format as timely and interactive as the developments it addresses.

Scope:

This journal is devoted to the applied science and engineering of aerospace computing, information, and communication. Original archival research papers are sought which include significant scientific and technical knowledge and concepts. The journal publishes qualified papers in areas such as real-time systems, computational techniques, embedded systems, communication systems, networking, software engineering, software reliability, systems engineering, signal processing, data fusion, computer architecture, high-performance computing systems and software, expert systems, sensor systems, intelligent systems, and human-computer interfaces. Articles are sought which demonstrate the application of recent research in computing, information, and communications technology to a wide range of practical aerospace engineering problems.

Individuals: $40 • Institutions: $380

To find out more about publishing in or subscribing to this exciting new journal, visit www.aiaa.org/jacic, or e-mail JACIC@aiaa.org.

AIAA

American Institute of Aeronautics and Astronautics

02-0744