Air Traffic Management Overview

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1. Introduction

The Air Traffic Control (ATC) system manages air traffic from various sources throughout the United States National Airspace System (NAS) [1]. The mission of air traffic control is “to promote the safe, orderly, and expeditious movement of aircraft [2].” The Federal Aviation Administration (FAA) is responsible for providing the NAS infrastructure to enable air operations in the United States, 24 hours a day, 365 days a year [3]. Air traffic control, the primary component of the NAS architecture, is a complex system comprising of many types of facilities, a plethora of hardware and software systems, and complicated interactions between humans and machines.

There are two goals that must be met by the Air Traffic Control system: safety and efficiency [1]. To ensure safety, minimum separation must be maintained between aircraft as they pass through the national airspace. Efficient air traffic control, however, requires that separation not be so great as to adversely affect the flow of traffic through the airspace.

This document comprises of the following:

- History of ATC and the evolution of the systems that comprise it.
- Overview of major facilities involved.
- Overview of current and future upgrade plans.
- Overview of new technologies being developed and associated research.

2. Background and Overview of ATC

2.1. Services provided by FAA

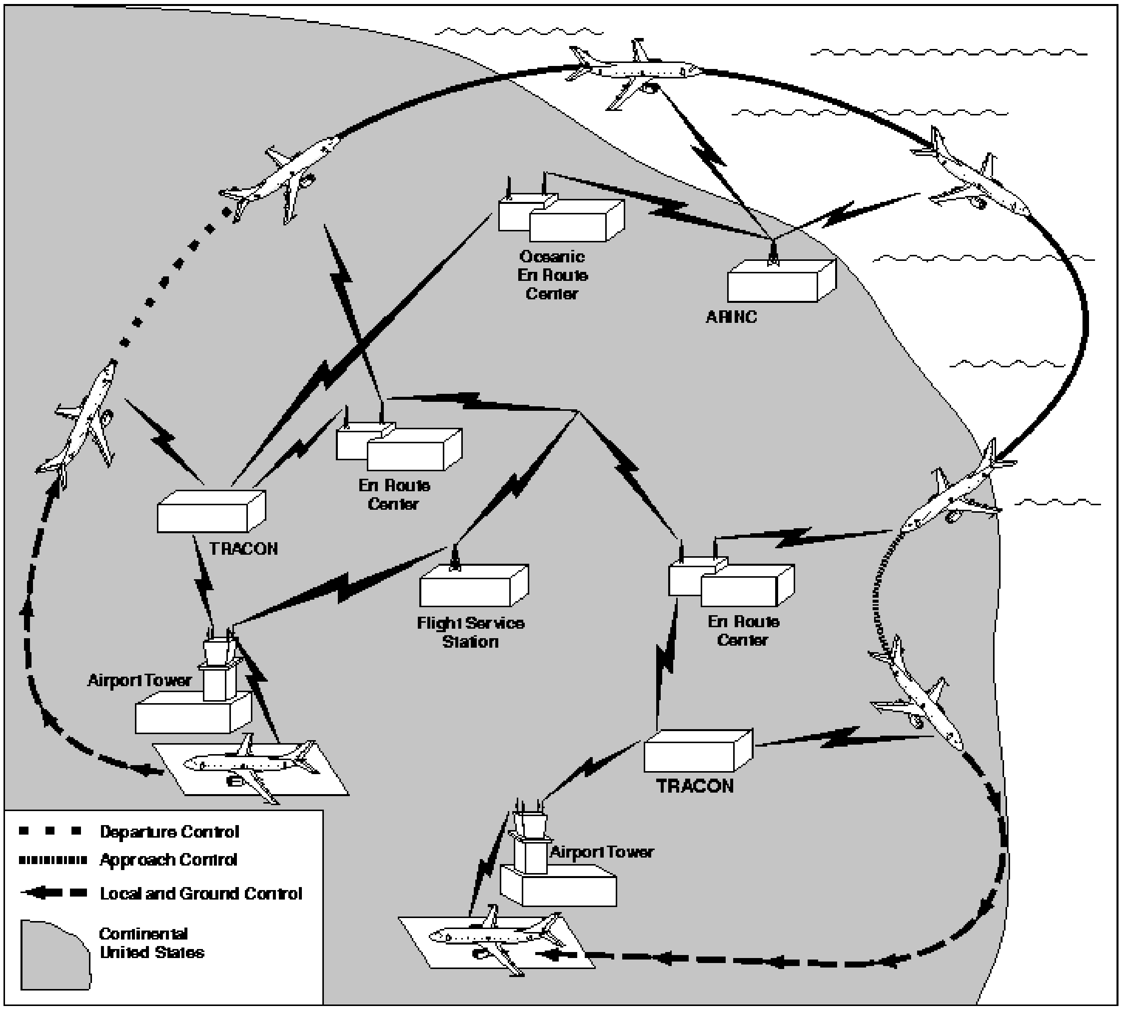

Figure 1: Overview of Air Traffic Control System [4]

The Air Traffic Control system is a complex system of systems [5]. The FAA provides air traffic services through four service areas that comprise of multiple complex systems. Figure 1 shows the interaction between the different facilities. Each of these service areas and their functions is described below [4]:

2.1.1. Air Traffic Control Towers

Airport towers control the flow of aircraft—before landing, on the ground, and after takeoff—within 5 nautical miles of the airport and up to 3,000 feet above the airport.

2.1.2. Terminal area facilities - Terminal Radar Approach Control (TRACON)
Direct aircraft in the airspace that extends from the point where the tower's control ends to about 50 nautical miles from the airport. A TRACON can be located at or outside an airport.

2.1.3. En route centers – Air Route Traffic Control Centers (ARTCC)
ARTCC control aircraft in air routes outside of terminal airspace. ARTCC Control is passed from one center to another as a plane moves across a region until it reaches terminal airspace. Two en route centers—Oakland and New York—also control aircraft over the ocean. Because radar coverage over the ocean is limited, beyond the radars' sight, controllers must rely on periodic radio communications through a third party—Aeronautical Radio Incorporated (ARINC), a private organization funded by the airlines and FAA to operate radio stations—to determine aircraft locations.

2.1.4. Flight Service Stations
FSS provides weather and flight plan services primarily for general aviation pilots.

2.2. The Past

Much of the air traffic control system in place today was designed in the 1960s and 1970s. In order to meet the demand for increased capacity and provide more reliable hardware and software, the Federal Aviation Administration (FAA) initiated a system modernization effort in 1981 [6]. This effort was riddled with failure. The initial competition to redesign the system began in 1984. In 1988, IBM Federal Systems won the $2.5 billion contract to build the next generation air traffic control system, the Advanced Automation System (AAS). Schedule slips occurred almost immediately on beginning the project. With the expected cost of completion placed at $7.6 billion in 1994, the FAA decided to cancel the project [7].

2.3. Current & Future

After the failure of the overly ambitious AAS plan – the FAA decided to upgrade the air traffic system in stages. Through its modernization program, the FAA is upgrading and replacing equipment and facilities—such as controller workstations and airport towers—and developing new CNS and automation technologies to help improve the safety, efficiency, and capacity of the NAS [4]. The current modernization plan is under an overall push to move towards Free Flight.

	Service areas			
Project's title	**Tower**	**Terminal**	**En route center**	**Flight service station**
Aeronautical Data Link	X	X	X	
Air Route Surveillance Radar-4			X	
Airport Surface Detection Equipment-3	X			
Air Traffic Control Beacon Interrogator			X	
Air Traffic Management/Free Flight Phase 1 Program		X	X	
Automated Surface Observing System	X		X	X
Display System Replacement			X	
Global Positioning System Program: Wide Area Augmentation System	X	X	X	
Global Positioning System Program: Local Area Augmentation System	X	X		
Host and Oceanic Computer System Replacement Program			X	
Integrated Terminal Weather System	X	X		
Oceanic Automation Program			X	X
Operational and Supportability Implementation System				X
Standard Terminal Automation Replacement System		X		
Terminal Digitization, Replacement, and Establishment Program/Airport Surveillance Radar-11 Project		X		
Terminal Doppler Weather Radar	X	X		
Voice Switching and Control System			X	
Weather and Radar Processor			X	

Note: "X" denotes service areas where projects are utilized.

Figure 2: List of Air Traffic Services that will be modernized by 18 major modernization programs [4]

The Free Flight modernization plan is broken up into phases. In the first phase (FFP1) 18 specific areas (Figure 2) have been identified for improvement. These areas are in various stages of upgrade. Out of the areas identified in Figure 2 this document describes:

- Free Flight Phase I initiative and related research programs.
- Automatic Dependent Surveillance – Broadcast (ADS-B)
- Global Positioning System (GPS) and its augmentations.

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3. Components of Air Traffic Control System

Before describing Free Flight and its enabling technologies, here is an overview of the key components of the Air Traffic System today.

3.1. Airport Tower

The airport tower is responsible for traffic management of all aircraft on the runways, as well as aircraft within 5 nautical miles of the airport and up to 3000 feet above the airport after take-off and before landing. The systems utilized by air traffic controllers at the Airport Tower to perform air traffic management are described in the following subsections.

3.1.1. Processing Systems

Flight Data Input/Output (FDIO) Computer

Flight strips are pieces of paper used to maintain local aircraft information, including the flight number, aircraft type, and clearances. Information on flight strips is communicated between the Airport Tower and TRACON using the FDIO Computer [1].

3.1.2. Display Systems

Digital Bright Radar Indicator Tower Equipment (DBRITE)

DBRITE is a radar display used to augment visual control of airborne traffic around the airport. Aircraft information from TRACON computer systems is displayed on the DBRITE radar screen, including information on aircraft not yet under Airport Tower control [1].

3.1.3. Radar Systems

Airport Surveillance Radar (ASR)

ASR is radar used to monitor the airspace around an airport. ASR-9 is the version of the system installed in the early 1990s; it is an IC-based radar that can track a target within 300 feet at a 20-mile range [7]. Raytheon is the contractor for the next generation ASR, which is the digital radar to be phased in between 1999 and 2007.

Airport Surface Detection Equipment (ASDE)

ASDE is ground surveillance radar to monitor the runways at an airport. ASDE detects both aircraft and ground vehicles [1]. The current version, ASDE-3, has been installed in 29 of 40 scheduled airports. It is high-resolution radar designed to overcome adverse weather conditions. The contractor is Northrop Grumman's Norden Systems Division [7].

3.2. Terminal Radar Approach Control (TRACON) Facilities

There are approximately 180 TRACONs across the United States, providing aircraft control approaching and leaving the busiest airports. In particular, the TRACONs are responsible for aircraft between 5 and 50 nautical miles of the airport and up to 10,000 feet above ground. The hardware and software systems present at the TRACON facilities are described in this section.

3.2.1. Processing Systems

Automated Radar Terminal System (ARTS)
The primary computer system at TRACONs is ARTS. ARTS coordinates information on aircraft from the FDIO computer and primary and secondary radar to maintain a data block on each aircraft. Information includes aircraft call sign, aircraft type, destination, and location. There are different versions of the ARTS computer system at the various TRACON locations; later versions provide automated monitoring and warning systems [1]. ARTS is composed of linked Sperry-Univac 1140 computers. A serious problem with ARTS computers is that they are acutely limited in memory [7].

Standard Terminal Automation Replacement System (STARS)
A replacement system salvaged from the failed Advanced Automation System effort is the STARS. STARS is intended to replace both the displays and the radar processors at the TRACON with a distributed computing system [7]. Raytheon is the primary contractor for STARS, which resolves information from multiple radars to track aircraft. The system is being developed in C to run on Sun UltraSparc UNIX workstations [7]. A detailed analysis of the STARS development effort is being conducted by the GAO [8].

3.2.2. Display Systems

Data Entry and Display Subsystem (DEDS)
Information from the ARTS computer system is displayed on DEDSs. The DEDS was designed in the 1960s and has reliability problems relating to the age of the equipment [7].

Full Digital ARTS Display (FDAD)
A more recent display facility for the ARTS computer system is the FDADs. In contrast to the DEDS, the FDAD was designed in the 1980s. It is a microprocessor-based system [7].

3.3. Air Route Traffic Control Centers (ARTCC)

There are 20 ARTCCs (also called En Route Centers) throughout the country, controlling aircraft in flight across the continental United States. Each En Route Center handles a region of airspace, responsible for commercial aircraft above 18,000 feet.

The 20 ARTCCs across the United States are found in the following locations [9]:

- Boston, MA	- New York, NY
- Washington, D.C.	- Jacksonville, FL
- Miami, FL	- Cleveland, OH
- Indianapolis, IN	- Atlanta, GA
- Chicago, IL	- Memphis, TN
- Minneapolis, MN	- Kansas City, KS
- Dallas-Fort Worth, TX	- Houston, TX
- Denver, CO	- Albuquerque, NM
- Salt Lake City, UT	- Seattle, WA
- Oakland, CA	- Los Angeles, CA

A description of the major hardware and software systems assisting controllers in the ARTCCs follows in this section.

3.3.1. Processing Systems

HOST Computer System

The HOST computer system was initially developed in the 1960s; during the 1980s it was "hosted" on new hardware. The HOST computer primarily processes flight data and radar data for display in the ARTCCs [1]. In addition, it provides alerts of possible aircraft separation violations and processes weather data [9]. The HOST computer system runs on IBM 3083 computers [7].

3.3.2. Display Systems

Plan View Display (PVD)

The PVD is the digitized display at En Route Centers showing estimates of the current location of radar targets using information from the HOST computer [1].

Display Channel Complex (DCC)

The DCC accepts radar and flight data from the HOST computer system and processes it for display on the controller screens, the PVDs. The DCC was designed in the 1960s and runs on IBM 9020E mainframes. Software running on the DCC is written in assembly language and JOVIAL [9].

Display Channel Complex Rehost (DCCR)

The increasingly frequent failures of the PVDs at the busiest En Route Centers necessitated a temporary fix for the DCC, called the DCCR. The DCCR replaces the 1960s IBM computers with an IBM ES/9121 mainframe to translate data from the HOST computer system for the PVD [7]. The two primary components of the DCCR are the Display Channel Rehost Processor (DCRP) and Display Controller and Switch (DC&S) [9].

Computer Display Channel (CDC)
The CDC is an alternative to DCC and its replacement system, DCCR, used in fifteen of the twenty ARTCCs and is not plagued with the same reliability problems as the DCC [9].

Display System Replacement (DSR)
DSR is a display-only system to replace the PVDs in ARTCCs with workstations that have no radar processing capability. DSR is a surviving component of the cancelled Advanced Automation System (it was to be the ISSS [9]), contracted to Lockheed Martin Corporation. The software is implemented in C and Ada running on IBM 6000 RISC workstations with the AIX operating system.

3.3.3. Radar Systems

Air Route Surveillance Radar (ARSR)
ARSR is three-dimensional, long-range radar for tracking aircraft through the ARTCC regions. Information is transmitted to the HOST computer system [7].

3.4. Air Traffic Control System Command Center (ATCSCC)

The ATCSCC is located in Herndon, VA. One of its primary functions is coordinating operations between En Route Centers by combining traffic flow. In addition, the ATCSCC establishes data flows for 28 major airports. The ATCSCC provides central flow control: primarily monitoring, not active participation. ATCSCC uses the HOST computer system to monitor traffic and has a data link to computers in Cambridge, MA for display purposes [1].

4. Suggested Future ATC System - Free Flight

4.1. Introduction

Today the Air Traffic Control system is overburdened. It is stretched to its limit and is not capable of meeting the expected increase in demand in the coming years. To rectify this the ATC System is being transformed to an Air Traffic Management (ATM) System. Here the air traffic controller will play an advisory role. With the support of various software tools, pilots will have greater control over the flight paths they fly and the in-flight decisions they make. This concept of greater control and lesser restrictions is termed as Free Flight.

Free Flight has been defined [10] as:
"… a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air Traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through Special Use Airspace (SUA), and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move towards Free Flight."

The aim of Free Flight is to enhance the aviation community's ability to collaboratively share data and to view and optimize all phases of flight - from planning and surface operations to en route flight paths [11]. Among the measurable benefits it provides are [11]:

- Lifting of restrictions
- Fuel savings
- Reduction in delays
- Increased airport acceptance rates during rush periods
- More efficient use of available runways and ramp operations

The implementation of Free Flight is broken up into phases. Free Flight Phase 1 (FFP1) was established in 1998 to deliver five "core capabilities" defined by the RTCA in documents [12,13,14]. FFP1 tools are to be in place by the close of 2002 [11]. Free Flight Phase 2 is now chartered to geographically expand upon the successes of FFP1 as well as to conduct research to alleviate congestion and provide greater access to the NAS [11]. The FFP2 timeline is from October 2000 through December 2005 [11].

4.2. Research Initiatives

The implementation of Free Flight is being done through various programs involving governmental and non-governmental agencies. Due to the vast scope of the project it is not possible to list all groups involved. Some of the research initiatives and relevant documents for the realization of Free Flight are:

- Distributed Air Ground Traffic Management Project (DAG-TM)
- NAS Architecture v4.0
- SafeFlight 21 Program
- Controller Pilot Data Link Communications (CPDLC) Program
- Aviation Safety Program (AvSP)
- European Programs

Note: This list is by no means exhaustive. It just highlights a few of the research initiatives.

4.2.1. Distributed Air/Ground Traffic Management (DAG-TM)

The Distributed Air/Ground Traffic Management concept outlines one possible implementation of Free Flight [15]. It is a NASA initiative under the Advanced Air Transportation Technologies (AATT) program. Various prototype technologies for Free Flight are being developed under this project.

The vision of DAG-TM project is characterized in the following statement [15]:
"Distributed Air/Ground Traffic Management is a National Airspace System concept in which flight deck (FD) crews, air traffic service providers (ATSP) and aeronautical operational control (AOC) facilities use distributed decision-making to enable user preferences and increase system capacity, while meeting air traffic management requirements. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS) / Air Traffic Management (ATM) technologies."

The DAG-TM concept offers two different perspectives for the development of new automation technologies. One is a ground based approach where automation tools will be developed to aid the controller on the ground and the other is an air based approach where automation tools will be developed to aid pilots on board aircrafts. The ground perspective is being explored by researchers at NASA Ames Research Center while the air perspective is being explored by researchers at the NASA Langley Research Center.

DAG-TM was formulated as a coherent set of solutions, known as concept elements (CE), to a series of key Air Traffic Management (ATM) problems. These problems are split into two main flight areas - en-route flight and terminal area flight. For each of these areas there are multiple concept elements describing the technologies that need to be developed for improving efficiency and throughput under Free Flight.

Under the ground based approach NASA Ames is developing a suite of automation tools called the Center-TRACON Automation System for terminal area. This system provides tools for planning and controlling air traffic in the Center-TRACON area. (Center here refers to ARTCC which control traffic from about 40 to 200 Nautical Miles (NM) around an airport) The tools being developed include:

- Final Approach Spacing Tool (FAST)
- Traffic Management Advisor (TMA)
- Descent Advisor (DA)
- User Preferred Routing (UPR)
- Direct-To Tool
- Expedite Departure Path (EDP)
- Collaborative Arrival Planning (CAP)

Each of these is described in detail at the CTAS website listed below.

Under the air based approach NASA Langley is developing and testing various different technologies. Currently its focusing on conflict detection and resolution for enroute airspace and self-spacing and self-merging in terminal area airspace. Self-spacing and self-merging refers to the concept of airplanes maintaining safe separation in-flight and during merges, without assistance from ground control. These goals correspond to DAG-TM CE-5 [16] and CE -11 [17]. They have also developed a medium-fidelity flight simulator to aid in the development of new technologies.

Further information:

- AATT: http://www.asc.nasa.gov/aatt
- CTAS: http://www.ctas.arc.nasa.gov/index.html
- Future Flight Central: http://ffc.arc.nasa.gov/
- AATT. "Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM)" Version 1.0. 30 Sep. 1999. http://www.asc.nasa.gov/aatt/dagconop.pdf

4.2.2. NAS Architecture V4.0

The NAS Architecture V4.0 the most recent document describing the plans for the modernization of the National Airspace through 2015. Many technologies described in it are essential for the success of various Free Flight initiatives.

The report is available at http://www.faa.gov/nasarchitecture/nasarch.htm

4.2.3. SafeFlight 21 Program

The Safe Flight 21 program is a three-year joint government/industry initiative. It is designed to demonstrate and validate, in a real-world environment, the capabilities of advanced surveillance systems and air traffic procedures associated with Free Flight. It uses Automatic Dependent Surveillance - Broadcast (ADS-B) and Traffic Information Services - Broadcast (TIS-B) as enabling technologies [18].

Specific goals and further information about the program can be found at http://www.faa.gov/safeflight21/intro/index.html

4.2.4. Control Pilot Data Link Communications Program (CPDLC)

The CPDLC allows for data communication between the pilot and the controller. This is supposed to supplement the current communication systems already in place. This will make it the exchange of routine and repetitive messages easier and less error prone.

Further Information:

- Plain English Overview http://usrwww.mpx.com.au/~cjr/cpdlc.htm
- http://38.243.118.34/products/cpdlc.htm

4.2.5. Aviation Safety Program (AvSP)

Safety is one of the main driving factors in the development of better technology for aviation. For successful adaptation of new Free Flight technologies it is essential that the new technologies are at least as safe as the current setup. The AvSP program is an initiative to reduce the aircraft fatal accident rate by a factor of 10 by 2022 [19]. It aims at not only reducing the aircraft accidents but also at reducing fatalities when accidents do occur.

Further information about the program can be obtained at: http://avsp.larc.nasa.gov/

4.2.6. European Programs

Even though the European Free Flight plan is different from the US plan there are many similar technologies being developed. This research can benefit our own research efforts.

Further information of the European Programs can be obtained at:

- EUROCONTROL: http://www.eurocontrol.be/
- NEAN, NAAN, NEAP Programs: http://www.vdlmode4.dk/
- NUP Program: http://www.nup.nu/
- FREER Program: http://www.eurocontrol.fr/projects/freer/freerflight.htm

4.3. Free Flight Phase 1 (FFP1)

FFP1 was chartered to achieve the limited deployment of five sets of tools described here. Figure 3 shows the area in which each of these tools is used [11]. These tools have been developed as part of various research projects and through contract by different companies like MITRE, Lockheed Martin, Boeing, and others. The actual status of deployment of each of these tools in the NAS is varied. The status of the implementation of FFP1 can be obtained from the monthly reports given to Congress by the FAA: http://ffp1.faa.gov/about/about_milestones_congress.asp .

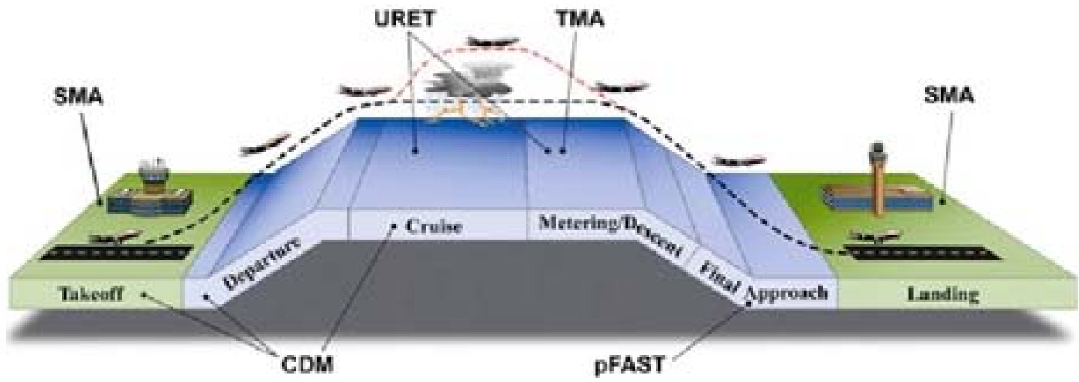

Figure 3: Tools and their Flight Areas [11]

4.3.1. Collaborative Decision Making (CDM)

Collaborative Decision Making provides airline operation centers and the FAA with real-time access to National Airspace System status information, including weather, equipment availability, and delays. This collaboration helps manage the airspace more efficiently. The three components of CDM are Ground Delay Program Enhancements, Initial Collaborative Routing, and National Airspace System Status Information.

4.3.2. User Request Evaluation Tool (URET)

User Request Evaluation Tool is a conflict probe that enables controllers to manage user requests in enroute airspace by identifying potential aircraft-to-aircraft conflicts up to 20 minutes ahead.

4.3.3. Traffic Management Advisor (TMA)

Traffic Management Advisor provides enroute controllers and traffic management specialists with the capability to develop arrival sequence plans for selected airports.

4.3.4. passive Final Approach Spacing Tool (pFAST)

passive Final Approach Spacing Tool maximizes runway utilization by providing controllers with aircraft sequence numbers and runway assignments according to user preferences and system constraints.

4.3.5. Surface Movement Advisor (SMA)

Surface Movement Advisor provides aircraft arrival information to airline ramp towers to assist airlines in better managing ground assets (gates, baggage operations, refueling, food service, etc.).

4.4. Current and Future Research Topics

FFP1 is just the beginning of the implementation of Free Flight. Over the next 20 years various new technologies will be implemented as part of FFP2 and FFP3. The research questions that need to be examined include:

- A study of long-term effectiveness of automation tools that expands on the metrics currently in use.
- Most of the current tools being deployed involve a controller and are based on a central computing paradigm. Current research initiatives are trying to develop systems to move from a central computing environment to a distributed environment. Here, the actual computation will take place on individual airplanes. This way a central computer facility does not need to be upgraded to add capacity. A distributed system also provides fault-tolerance, as it removes the single point of failure.
- Tools providing greater control to pilots like automatic Conflict Detection and Resolution (CD&R) and self-spacing for en-route and terminal area flight.
- To enable automatic CD&R and self-spacing, airplanes will need to track surrounding traffic and know the intent of the traffic in some cases (especially terminal area). Challenges in implementing this automation lie in defining the exact form of this information, and in developing technologies to broadcast this information.
- Developing a concrete plan that balances airborne automation with ground based automation.

5. Enabling Technologies

This section describes two major technologies essential for the success of free flight. At the time of writing Boeing Corp. has announced that it is going to develop a completely satellite based navigation system to work with GPS. Details are minimal but if this new system succeeds it might take the place of some of the GPS augmentations described below.

5.1. Automatic Dependent Surveillance – Broadcast (ADS-B)

5.1.1. Overview

- ADS-B is a technology that allows the broadcast of aircraft information like type, speed, and altitude. This broadcast information can be received by other aircraft in the area and can be displayed in the cockpit.
- ADS-B relies on GPS instead of Radar.
- Unlike conventional radar, ADS-B works at low altitudes and on the ground, so that it can be used to monitor traffic on the taxiways and runways of an airport.
- Air Traffic controllers and pilots have access to the same real time data

5.1.2. How does it work?

- Based on GPS signals, the ADS-B system converts aircraft position into a digital code, which is combined with other information such as the type of aircraft, its speed, its flight number, whether it's turning or climbing or descending. Then this information is broadcast to the surrounding traffic through a datalink.
- Other aircraft and ground stations within about 150 miles receive the datalink broadcasts. Pilots in the cockpit see the surrounding traffic on a Cockpit Display of Traffic Information (CDTI). Controllers on the ground can see the ADS-B targets on their regular traffic display screen along with other radar targets.

5.1.3. Benefits

- Higher Traffic Awareness for pilots.
- Provides information enabling the implementation of automatic CD&R and Self-Spacing.
- Final Approach Spacing
- Departure Spacing
- Airport Surface Situational Awareness
- Runway Occupancy Alerting

5.1.4. Enabling Technologies

- GPS – Global Positioning System
- Communication Datalink
    - For this various possible candidates are:
        1. VDL (VHL Digital Link) Mode 4
        2. UAT (Universal Access Transceiver)
        3. Mode S Extended Squitter

- Each of these have various advantages which need to be looked into

5.1.5. Further Information

The following resources provide detailed information about ADS-B and its components.

- A Complete Overview of ADS-B: RTCA DO-242
- ADS-B Website:http://www.ads-b.com/Content/index.htm
- 1999 ADS-B OpEval Final Report: http://www.ads-b.com/Content/plan/1999FinalReport.pdf
- ADS-B and Terrorism: http://www.airsport-corp.com/adsb2.htm
- FAA ADS-B Description: http://www.faa.gov/and/and300/datalink/navsur/adsb.htm

5.2. Global Positioning System – GPS

5.2.1. Overview

GPS is a satellite based navigation system developed by the U.S. Department of Defense for military purposes. Due to the wide variety of benefits that GPS provides to the user community it was made available for civilian purposes. Today its civilian use has far exceeded its military use. GPS is used in various fields like archeology, mining, public safety, space applications, and infrastructure development to name a few. But it is most useful in the field of Transportation – Air, Road, Rail and Marine.

5.2.2. How does it work?

There are 24 GPS satellites in orbit. With the use of 3 satellites an exact position on earth can be triangulated. This triangulation is done by measuring the distance from each satellite to the point of interest. To calculate this distance GPS uses very accurate timing devices, which measure the time it takes for a signal to reflect back to the satellite from the point of interest. Based on this data and the current position of the satellite the position of the point of interest can be found very accurately.

5.2.3. Air Traffic Management and GPS

The success of Free Flight is linked with the use of GPS. The two main areas that GPS will play a critical role in are safe navigation of airplanes and Air Traffic Control (ATC). To make this possible various tools like ADS-B, URET, TMA, SMA and others have been developed. All of these require real-time position data of the aircrafts in air or on ground. GPS provides this data in an easy way. Currently, the FAA is trying to determine the risks associated with making GPS the primary means of navigation and ways to overcome these risks.

5.2.4. Risks Associated with GPS

- GPS signal is susceptible to interference, jamming and spoofing. This is due to the low power of GPS signal [20].
- Failure of GPS equipment
- Need to monitor integrity of signal

- Tools dependent on GPS.

5.2.5. GPS Augmentations

In spite of the high accuracy of GPS it is still not accurate enough to be used on its own for aviation applications. Moreover because of its low signal strength and susceptibility to interference there needs to be a way to validate the signal being received by the airplanes from GPS. This is going to be done through two systems that will augment GPS.

5.2.5.1. Wide Area Augmentation System (WAAS)

As the name suggests, WAAS augments the GPS signal by making it more accurate. The added accuracy will make it possible for GPS to be the primary means of navigation for en-route and non-precision approaches. WAAS consists of 25 wide area ground reference stations (WRSs) placed strategically across the United States. These WRSs receive the GPS signals and check their accuracy. Then they generate a correction signal and transmit it back to the GPS satellites. This correction signal is then transmitted along with the GPS signal to all receiving airplanes. This way the signal accuracy as well as validity can be checked.

5.2.5.2. Local Area Augmentation System (LAAS)

LAAS was developed to work with WAAS to provide the ability to GPS to become the primary means of navigation for all areas of flight. LAAS works similarly to WAAS except it broadcasts the correction signal using VHF Datalink. LAAS stations are placed around the terminal areas where their broadcast signals can be picked up by airplanes. This way GPS can be used in terminal area.

5.2.6. Further Information

The following resources provide detailed information on GPS and its components.

- JHUAPL report on GPS Risks: http://www.jhuapl.edu/transportation/aviation/gps/gps.pdf
- Overview of GPS: http://www.trimble.com/gps/
- GPS at FAA: http://gps.faa.gov/
- GPS at VOLPE: http://www.volpe.dot.gov/gps/overview.html
- Institute of Navigation: http://www.ion.org

6. Conclusion

This report presents a detailed investigation of the Air Traffic System. It provides a glance at the current and future research efforts, and technologies that enable Free Flight. We can infer that the ATS system is extremely complex, very large, and exposed to a number of different threats. The key characteristics of new ATS technologies are: very-high dependability requirements; very serious consequences of failure; and well defined survivability requirements.

At this stage it is difficult to predict the final form of the ATM system. In reality because of its complexity the ATM system will be constantly evolving with the development of new technologies. The only thing that can be said for certain is that over the next few decades, automation will become central to flight and flight management. Before this can occur, major challenges in the development of reliable and complex safety critical software systems need to be overcome.

Appendix A – References

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Appendix B – Acronyms

AAS	Advanced Automation System
AATT	Advanced Air Transportation Technologies
ACCC	Area Control Computer Complex
ACTD	Advanced Concept Technology Demonstrations
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Centers
ARTS	Automated Radar Terminal System
ASAS	Airborne Separation Assurance System
ASDE	Airport Surface Detection Equipment
ASOS	Automatic Surface Observing System
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-A	Automatic Dependent Surveillance – Addressed
ARTCC	Air Route Traffic Control Centers
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASR	Airport Surveillance Radar
CD&R	Conflict Detection and Resolution

CDC	Computer Display Channel
CDTI	Cockpit Display of Traffic Information
CNS	Communication, Navigation and Surveillance
CONUS	Continental United Status
CTAS	Center TRACON Automation System
DBRITE	Digital Bright Radar Indicator Tower Equipment
DCC	Display Channel Complex
DSR	Display System Replacement
FAA	Federal Aviation Administration
FDAD	Full Digital ARTS Display
FDE	Fault Detection and Exclusion
FREER	Free-Route Experimental Encounter Resolution
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCS	HOST Computer System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
LAAS	Local Area Augmentation System
LORAN	Long Range Navigation
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NPA	NonPrecision Approach
PRM	Precision Runway Monitor

RAIM	Receiver Autonomous Integrity Monitoring
SMA	Surface Management Advisor
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace
TCAS	Traffic-alert and Collision Avoidance System
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
WAAS	Wide Area Augmentation System

Appendix C – Research Resources

C.1. Websites

Free Flight

Air Traffic Management Systems: UCBerkley, NASA Ames Project Page
CTAS - Center Tracon Automation System
DAG-TM Justification Paper
FAA: Main Page
Free Flight
French Aerospace (CENA)
LORAN-C: What is it and all other details
NASA and the FAA
NASDOCS: National Airspace System Documents
NLR: Traffic Manager
Paper on TMA (Traffic Management Advisor): Describes that it actually works
SafeFlight 21
Technical NASA reports - Search
TMA - Traffic Management Advisor: NASA Ames
URET Main Page :User Request Evaluation Tool - MITRE

Automatic Dependent Surviellence – Broadcast (ADS-B)

ADS-B
FAA description of ADS-B
MITRE and ADS-B
Will ADS-B increase Safety & Security of Aviation

Global Positioning System (GPS)

GPA at FAA
GPS 2000 Conference - ION: List and descriptions of Papers
GPS Application Exchange
Institute of Navigation
ION January Conferece (22-24) 2001
JHUAPL Report on GPS Risks: PDF Document
NAVSTAR GPS Joint Programs Office
US Navy GPS
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C.2. Documents

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