Project Report

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An Assessment of the Communications, Navigation, Surveillance (CNS) Capabilities Needed to Support the Future Air Traffic Management System

S. Thompson
D. Spencer
J. Andrews

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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16. Abstract

The purpose of this study was to assess the Communications, Navigation, and Surveillance (CNS) capabilities needed to support future Air Traffic Management (ATM) functionality in the National Airspace System (NAS). The goal was to determine the most effective areas for research and technical development in the CNS field and to make sure the decision support tools under development match future CNS capabilities. The requirements for future ATM functions were derived from high level operational concepts designed to provide more freedom and flexibility in flight operations and from the Joint Research Project Descriptions (JRPDs) that are listed in the Integrated Plan for Air Traffic Management Research and Technology Development. This work was performed for the FAA/NASA Interagency Air Traffic Management Integrated Product Team.

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1. INTRODUCTION

The purpose of this study was to assess the Communications, Navigation, and Surveillance (CNS) capabilities needed to support future Air Traffic Management (ATM) functionality in the National Airspace System (NAS). The goal was to determine the most effective areas for research and technical development in the CNS field and to make sure the decision support tools under development match future CNS capabilities. The requirements for future ATM functions were derived from high level operational concepts designed to provide more freedom and flexibility in flight operations and from the Joint Research Project Descriptions (JRPDs) that are listed in the Integrated Plan for Air Traffic Management Research and Technology Development [1]. This work was performed for the FAA/NASA Interagency Air Traffic Management Integrated Product Team.

The essential questions to be answered in this assessment are:

1) What CNS capabilities are required to support envisioned ATM concepts?

2) What are the predicted future CNS capabilities in terms relevant to ATM concepts?

3) What are the CNS shortfalls?

4) What are the principal CNS-related risks that should be monitored and/or reduced?

5) What are the missed opportunities for exploiting CNS capabilities?

The approach taken is to first define the high level operational concepts being considered for future ATM systems that support more flexibility and freedom in flight operations. Next, a summary of the future ATM functions and CNS needs is derived from the operational concept definition. An assessment is made of the current relevant CNS capabilities and prospects for future CNS capabilities. Next, there is a review and discussion of the CNS/ATM issues that need to be resolved in order to achieve the future ATM functionality. Following that is a review of the Joint Research Projects to characterize their relationship to the CNS issues and address any CNS related requirements that might be needed. Finally, all of the identified issues are summarized by CNS category.

2. CNS CHARACTERISTICS

ICAO defines CNS/ATM as follows:

> "Communications, Navigation, and Surveillance systems, employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global Air Traffic Management system."

This definition does not seem especially clear in distinguishing between those aspects of the system that are relevant and those that are not. Hence, we will define the term "CNS" as follows:

CNS encompasses those elements of the global Air Traffic Management system associated with real time acquisition and transmission of operationally relevant information on aircraft position, identification, meteorological phenomena, system status, and ATM control actions. It includes the parts of the aircraft system associated with control of own aircraft position using acquired data.

From this perspective, CNS can be viewed as consisting of surveillance systems that acquire selected data about the world and communication systems that transmit that data from the point of acquisition to the various users. The surveillance data is primarily aircraft positions, but it may also include winds, locations of hazardous weather, turbulence, volcanic ash, etc. Navigation can be viewed as a special case of acquiring one's own position and using it to attain a desired trajectory. If the use of the data involves substantially more than simply displaying basic data to the user, then the associated subsystems will often be considered to be within the realm of ATM rather than CNS.

With the above paradigm, we can begin to examine CNS systems to determine whether they meet the requirements for support of new ATM services. Clearly, a statement such as "An air-ground data link will be available" does not settle the question of whether there will be adequate communication capability to support a particular ATM function, such as air-to-air separation. To address the relevant questions, it is helpful to identify the salient characteristics of CNS systems that are critical to their adequacy in a given context. Among the significant characteristics are the following:

- Data content: What data does the CNS system acquire?
- Coverage: Over what physical extent does the CNS system operate?
- Capacity: How many users can the system support?
- Accuracy: What are the error characteristics during normal operations?
- Latency: How current is the data delivered to users?
- Reliability/Integrity: How often does the system provide corrupt or unusable data?
- Security: Is the system sufficiently resistant to deliberate attack?

- Availability: How often is the system unavailable for use?
- Equipage: What fraction of users will be equipped to use the CNS system?
- Deployment Schedule: On what schedule will the CNS capabilities be deployed?
- Cost: What is the cost, to both service providers and users, of acquiring and maintaining the CNS capabilities?

In general, a CNS system will have to be adequate with regard to all the above characteristics in order to allow a particular ATM capability that relies upon the CNS system to be successfully implemented.

In assessing CNS/ATM capabilities, there is clearly great uncertainty in looking very far into the future. Some characteristics of future CNS systems may be uncertain. And even more uncertainty usually attends the requirements of ATM innovations that are still in the research stage. Hence, we should not expect exact answers to questions regarding CNS/ATM requirements. It is more appropriate to simply classify the degree of risk involved in a particular area.

For example, in the future ATM system there will be a need for extensive data communications between aircraft and ground facilities, between different ground facilities, and even between aircraft. The communications implementation must be flexible and multi-layered, serving different users, different equipages, different service providers, etc. It must grow and evolve as new services appear and as older services are upgraded. It must serve lower priority, strategic data transfer that supports ATM efficiency while providing for high priority, time-critical communication for safety-critical services.

The way in which we are developing, certifying, and implementing communication services often works against achieving this degree of flexibility. We find it easier to take things one short step at a time without going too far out of our way to allow for future growth. Sometimes this is motivated by the need to ensure adoption of communication standards and stimulate equipage with the necessary avionics. Concept developers who come along later often find themselves limited to exploiting pre-existing capabilities because implemented systems cannot be easily modified to serve new purposes.

One way to address the problem would be to define the future operational concept in detail and then impose the CNS requirements well in advance of the implementation period. But this can be difficult to do when the operational concepts are not fully defined and are evolving with experience and research. To ensure that future ATM innovations can be implemented in a timely manner, it may be necessary to focus instead upon providing sufficient flexibility for meeting unanticipated or newly emerging requirements. The need for flexibility must be accepted as a requirement that is just as important as the need to serve a particular near-term implementation. This is not a technical issue so much as an institutional and cultural issue. And it needs to be addressed on a global basis.

3. FUTURE ATM OPERATIONAL CONCEPTS

There are various short term and long term future Air Traffic Management (ATM) operational concepts that have as their goals improving efficiency in air traffic flow and allowing more flexibility and freedom for aircraft operators to choose their flight paths. These operational concepts range from centralized ground-based systems that receive requests and issue approvals for four-dimensional trajectories for individual aircraft to autonomous self-separation schemes. Each particular operational concept has specific CNS implications. In order to characterize the ATM functions and CNS needs to support whatever future ATM system may evolve, it is necessary to consider the range of operational modes.

Potential operational concepts for any ATM function can be categorized along the following dimensions:

- Ground-based vs. Airborne – is the function performed at a ground facility or on the flight deck?
- Centralized vs. Distributed – is the function performed at a single location for all flights, or do multiple facilities each manage a portion of the airspace or a portion of the flights, and coordinate when they might affect the responsibilities of another facility?
- Autonomous vs. Collaborative – does the ATM domain (e.g., surface, en route) responsible for performing a given ATM function negotiate with other ATM domains that have a stake in the outcome and whose objectives may be different?

A classification system introduced by EUROCONTROL and presented in a paper by Duong, *et al.* [2] defines three Operational Modes of Control to describe the spectrum of autonomy granted to airspace users:

- Ground-based Centralized Control
- Ground-Air Coordinated Control
- Airborne Autonomous Control

There are five Operational Components of the generic Operational Modes of Control:

- Airspace Routing
- Flight Management
- Separation Assurance
- Demand Capacity Balancing ("Flow Control")
- Airspace Allocation

Table 1 describes the Operational Components across the spectrum of generic Operational Modes of Control. This serves to illustrate the range of operational concepts envisioned for future ATM.

Table 1. Operational Components for Three Generic Air Traffic Operational Modes

	Airspace Routing	Flight Management	Separation Assurance	Demand Capacity Balancing	Airspace Allocation
Centralized Ground	Fixed-Route	Externally Managed	Centralized	Global	Strategic
Coordinated (Ground/Air)	User-Preferred	Distributed Ground/Air	Cooperative	Global	Strategic & Tactical
Autonomous (Air)	Free-Route	Self-Managed	Airborne Extended Flight Rules	Local	Tactical

In the Ground Based Centralized Control Operational Mode the aircraft Flight Management, defined as the determination of the flight path of an aircraft, is made external to the aircraft along fixed trajectories that are guaranteed conflict free. The Separation Assurance is centralized on the ground. Aircraft may request a different trajectory, but the ground determines if that trajectory is approved or not. Airline Operations Centers file for flight profiles in advance to fit airport arrival slots and Airspace Allocation is determined by a Central Flow Management Unit. The Airspace Allocation could be adjusted prior to take-off to account for dynamic changes in weather, winds, active military airspace, etc. The Central Flow Management Unit determines the required Demand/Capacity Balancing for both airports and en route airspace.

In the Coordinated Ground/Air Operational Mode, the users choose preferred trajectories coordinated with the ground. The ground acts as the depository of current surveillance data, trajectory predictions, and conflict detection and resolution tools. Traffic control and separation is directed by the ground but accomplished by the aircraft adjusting the trajectory within acceptable bounds. Conflict Detection and Resolution is primarily on the ground. Flight Management is in the aircraft, and Separation Assurance is shared between the ground and the aircraft. Airspace Allocation is both tactical and strategic. Demand/Capacity Balancing remains global.

In the Autonomous Operational Mode Airspace Routing is free and Flight Management is entirely self managed. Extended Flight Rules (EFR) are followed to accomplish Separation Assurance in the air. The EFR concept is an extension of Visual Flight Rules (VFR) and Autonomous Flight Rules (AFR) that assigns a priority to aircraft during encounters. Specific rules are designed to designate which aircraft should give way or maneuver to avoid loss of separation. During normal flight, aircraft will be required to broadcast an intention of change in trajectory and the trajectory must be conflict free within the air-to-air surveillance range. In the event a conflict is later detected while flying the trajectory, EFR will coordinate between aircraft in a TCAS like manner and assign unambiguous priority between the aircraft on the order of 10 minutes prior to loss of separation. Demand/Capacity Balancing is local and Airspace Allocation is tactical.

The assumption made in this report is that the trend with time will be from a Ground Based Centralized Operational Mode, to a Coordinated Ground/Air Operational Mode, and finally, perhaps to an Autonomous Operational Mode. Communications, Surveillance, and Navigation will need to support the Ground-based Operational Mode in the near future but the infrastructure needs to be in place to support the Coordinated Ground/Air Operational Mode and the Autonomous Operational ATM functions that may be needed further in the future.

4. SUMMARY OF FUTURE ATM FUNCTIONS AND CNS NEEDS

For all of the Operational Modes described above, ATM must provide certain functions to achieve safe, efficient traffic flow. These include separation assurance, the detection, forecast, and dissemination of hazardous weather, and tools to optimize the use of the available assets (airports and airspace). There are plans to allow user inputs for optimization of their services.

4.1 Separation Assurance

Currently, individual air traffic controllers working a fixed geographic sector with aircraft flying along fixed paths provide separation assurance. Coordination with other sectors is limited to agreements on routes, "miles in trail" spacing, and one aircraft at a time acceptance of separation responsibility by the next controller.

4.1.1 Trajectory Prediction and Conflict Resolution

Any of the Operational Modes of Control for future ATM will require trajectory prediction and conflict resolution. However, the uses for trajectory prediction and conflict resolution fall into three different categories and each imposes different CNS needs.

First, there is the need for long-range predictions for strategic flow planning. This is accomplished now with flight plans automatically filed by the Airline Operation Centers (AOCs), but the increased sophistication of future ATM systems may require a more accurate forecast of planned trajectories consistent with the flexibility afforded operators. Strategic planning for hazardous weather avoidance requires forecasts of trajectories more detailed and timely than those afforded by flight plans alone.

There is a need for conflict detection and resolution between individual aircraft. The required look-ahead time has not yet been clearly specified. If the look ahead time is too far, there will be false alerts because there will be too much possibility for changes or miss-estimation of trajectories. If the look-ahead time is too short, the resolution maneuver may be inefficient and may be unreliable if there are more than two aircraft involved. Most operational concepts now estimate that the strategic trajectory prediction and conflict detection and resolution function will need to look ahead approximately 15 to 30 minutes. This can be accomplished on the ground with current surveillance. Depending on the specifics of the operational concept, aircraft intent can be transmitted by voice from the flight deck. More advanced concepts will require a data link to send aircraft intent. For some functions, intent may be inferred from the Flight Management System (FMS) or aircraft state (heading, turn rate, indicated airspeed).

There is also a need for tactical trajectory prediction and conflict resolution in the two to five minute range for Coordinated Ground/Air or Autonomous Air Operational Modes. This may require air-to-air surveillance (e.g., ADS-B), Cockpit Display of Traffic Information (CDTI), and a two-way data link between aircraft with coordinated resolutions. The Airborne Collision Avoidance System (ACAS) will remain an independent collision avoidance system.

4.1.2 Airborne Autonomous Separation

Airborne Autonomous Operational Mode of Control speculates that aircraft will accept full responsibility for separation. In the near term, there will be a limited transfer of self-separation under very specific conditions. Limited specific self-separation such as maintaining an in-trail separation distance may be accomplished with CDTI alone. However, self-separation on a larger scale must involve a transfer of data between aircraft that results in unambiguous reliable coordinated maneuver instructions to resolve loss of separation predictions. The flight decks of all aircraft must have access to the projected trajectories of other aircraft and must be aware of proposed trajectory changes. The domains where airborne autonomous separation may be introduced include oceanic, en route, and closely-spaced parallel approaches.

4.1.2.1 Oceanic

Airborne self-separation is of clear interest in oceanic airspace. Limited use of ACAS displays has already been accepted for some oceanic passing maneuvers. These require voice communications between the pilots. Extended use of self-separation might allow reduced lateral and longitudinal separation. This will require CDTI and possibly require updates of the Inertial Navigation System (INS) by GPS.

4.1.2.2 En route

It is envisioned that the introduction of self-separation into the en route airspace would be an extension of the use in oceanic airspace. This might consist of procedures such as maintaining in-trail spacing assignments. The Operational Modes of Control described above envision more autonomous control using CDTI. In any event, accurate navigation (e.g., GPS), and CDTI would be required for the initial en route operations. Airborne autonomous conflict prediction and resolution advisories would require aircraft-to-aircraft data link with aircraft intent information exchanged between aircraft.

4.1.2.3 Closely-Spaced Parallel Approaches

Closely-spaced parallel approaches in Instrument Meteorological Conditions (IMC) offer near term benefits to equipped aircraft but there are some special considerations. Current procedures for closely-spaced parallel approaches in IMC are based on high update rate ground-based surveillance with alerting algorithms designed to warn controllers and pilots of blunders in time for controllers to issue breakout advisories to the pilots. The time required from the detection of a blunder to the start of avoidance maneuvering puts a practical limit on how close the parallel approaches can be safely conducted. Currently, the limit for independent dual approaches is 3400 feet between centerlines with a Precision Runway Monitor (PRM) system consisting of a high update radar, a 2000-foot no transgression zone, a Final Monitor Aid (FMA) and a dedicated controller at the Final Monitor Position. This constrasts with a minimum runway separation of 750 feet that is allowed for parallel visual approaches.

The objective of the Airborne Information for Lateral Spacing (AILS) program at NASA is to provide the technology necessary for flight crews to assume responsibility for aircraft separation during closely-spaced parallel approaches in instrument weather. The goal is to approve approaches to closely-spaced parallel runways in IMC with a capacity similar to that obtained in Visual Meteorological Conditions (VMC). The specific goal of AILS is to support independent instrument approaches in IMC to runways spaced as close as 2500 feet apart. This requires accurate navigation and cockpit alerts of aircraft deviations that threaten other aircraft on the parallel approach. Technologies that could potentially be used to implement this concept include Differential Global Positioning System (DGPS) for accurate navigation and ADS-B to broadcast aircraft position and state information such as track and rate of turn. The ADS-B data will be used by other aircraft to maintain an accurate fix on the aircraft. AILS will use this information to aid in automatic alerts in the event that one aircraft strays from its course and approaches the path of another aircraft on the parallel approach. The alerting algorithms and associated safety analysis are predicated on a fixed escape maneuver that the evading aircraft will execute in the event of a potential collision. The research to date has focused on providing TCAS-like display guidance during collision avoidance maneuvers. A secondary goal of the AILS research is to investigate solutions for runways spaced closer than 2500 feet apart. One concept being investigated is the paired-staggered approach.

The paired-staggered concept depends on a fundamentally different approach to collision avoidance. The trail aircraft positions itself on the parallel course sufficiently behind the lead aircraft so that a collision is all but physically impossible during any blunder. However, the trail aircraft must remain ahead of any wake from the lead aircraft that might cross over to its path. The trail aircraft is required to station keep within a box approximately one half mile in length parallel to and behind the lead aircraft. This requires a specialized CDTI display in the trail aircraft. The lead aircraft must report its position using ADS-B. There are operational concepts that have been proposed that use a ground-based high update surveillance system to provide the lead aircraft's position reports so that there is no requirement for the lead aircraft to be ADS-B equipped.

4.2 Hazardous Weather Detection, Forecast and Dissemination

Currently, ground-based weather radar provides air traffic control with weather information. This information is most detailed near major airports which may have Terminal Doppler Weather Radar (TDWR) and sophisticated microburst, thunderstorm, and gust front tracking and forecasting algorithms contained in the Integrated Terminal Weather System (ITWS). En route coverage may not be as complete. Commercial aircraft depend on airborne radar. Smaller general aviation aircraft may have lightning detection devices or may have to rely on weather available verbally from the air traffic controller or flight service station specialist. The air traffic controller may not have access to the TDWR or ITWS products at his or her display.

Future ATM functions need a common reliable complete weather database available to all users. This is needed to determine available routes and hazardous areas to avoid as well as acceptance rates at airports. It is also needed to increase safety of non-radar equipped aircraft. This will require an airborne data link for those aircraft.

4.3 Airspace Utilization Optimization

4.3.1 Airport and Terminal Airspace

The Center/TRACON Automation System (CTAS) is an automation system under development that will provide conflict free guidance, sequencing, runway assignment, and active spacing advisories for aircraft arriving in the terminal area at major airports. CTAS comprises the Traffic Management Advisor (TMA) that sequences the aircraft through arrival fixes, the Descent Advisor (DA) that provides conflict free fuel efficient descent advisories, and the Final Approach Spacing Tool (FAST) for advisories that provide minimum safe spacing. TMA allows controller inputs and overrides and is designed to accommodate route closures. Currently FAST has been implemented as passive FAST (pFAST) and only provides sequence and runway assignments. Active FAST (aFAST) is still in the development stage.

Expansion of CTAS to handle more complicated airport arrival patterns and multiple airports is planned. Some evolution of CTAS is envisioned as the future airport and terminal airspace optimization tool.

Future needs will involve integrating departure flow management (both runways and airspace) and surface movement with CTAS.

The CNS need is for surveillance data merged from all sources that track arrivals out to the planning horizon. It is not generally sufficient to rely solely on the TRACON radar for surveillance. There is also a need for integration of planned departures from nearby satellite airports into arrivals already under surveillance and included in the scheduling algorithm. Trajectory generation algorithms need accurate high resolution three dimensional wind field data and access to aircraft data such as weight or final approach speed from the AOC or aircraft. Severe weather forecasts are needed so that arrival gate and airport or runway closures can be scheduled thirty minutes or more in advance. Accurate ceiling and visibility forecasts are needed to forecast airport acceptance rates. If accurate information on hazardous weather regions was available to CTAS, it might be possible to extend the conditions under which it can be used to those that require routing traffic around hazardous weather.

4.3.2 En route Airspace

Existing capabilities are limited to fixed routes with case by case direct routing. In certain low traffic density areas at high altitudes, direct routing is routinely granted. The capability is limited by a lack of support tools for the controller and the fact that the airspace is divided by sectors under the supervision of individual controllers. The Severe Weather Avoidance Program (SWAP) is a first attempt at minimizing the effects of traffic flow disruptions due to hazardous weather. SWAP involves making use of pre-determined route changes to accommodate route interruptions due to hazardous weather.

The User Request Evaluation Tool (URET) is a prototype trajectory prediction and conflict detection and resolution tool. Flight trajectory history and flight plan information are the data available for predictions. The tool is not used directly by the active controllers. It does have the capability of providing advisories to controllers in one sector for preventing future conflicts in other sectors.

Ultimately, decision support tools that support free flight will lead to more efficient use of en route airspace.

4.4 Collaborative Decision Making

Collaborative decision making is envisioned to be the process whereby Airline Operations Centers (AOCs) work directly with air traffic managers to optimize their own use of air traffic resources. Currently AOCs are only able to swap ground delays among their own flights that have received ground hold delays to a common destination. There is not a detailed operational concept describing how AOCs are expected to interact with ATM in the future. The CNS needs in this area will depend on the operational concept.

5. ASSESSMENT OF CNS CAPABILITIES

5.1 Communications

Parts of the following section were taken from an analysis by Boisvert, *et al.*, for the Air Force [3].

The VHF aeronautical communications band is currently divided into 25 kHz channels that are used for both voice and data communication between aircraft and ground. Voice is used for the ATC portion of Air Traffic Services (ATS) communication and for airline operations. Data transmission is currently used primarily for Aeronautical Operational Control (AOC) communication with airline operations centers. The planned evolution of ATS communications is based on a digital communication network infrastructure, and VHF digital links for ATS use are planned for the near term. VHF aeronautical communication requirements thus address both voice and data capabilities for both ATS and AOC applications.

5.1.1 Voice Systems

Air traffic controllers conduct their work using voice communication with aircraft pilots on the ground and in the air. There is a limit to the number of aircraft that can be controlled in this manner by a single air traffic controller. As the volume of air traffic grows, current ATC techniques require that the airspace be re-sectored, and more controllers added to the ATC system, together with more voice channels. The VHF aeronautical communications band used for ATS and AOC has become overcrowded because of the growth of air traffic to the point where it is becoming difficult to add the new communication channels needed in certain regions. The international standard for ATC voice communication is double sideband, amplitude modulation (DSB-AM) of analog voice using 25 kHz channels in the VHF band. There are over 700 such 25 kHz VHF channels in use worldwide for ATS and AOC communication.

The need for additional VHF voice channels has become so acute in Europe that a new analog voice system is being introduced this year. This system divides existing 25 kHz analog voice channels into three 8.33 kHz analog voice channels, and will be referred to here as "8.33 kHz voice."

Another alternative being considered by ICAO is called VHF Digital Link Mode 3 (VDL Mode 3 or just VDL-3). VDL-3 is based on transmission of voice or data in digital form using time division multiple access (TDMA) technology for sharing a single 25 kHz channel among three or four sub-channels. Each sub-channel can be assigned to either voice or data functions, with a ground station managing the assignment of sub-channels to the various uses. Three sub-channels are expected to be used in en route airspace to provide sufficient guard time for long range communication, while four sub-channels would be used for shorter range (terminal area) communication. Because of its potentially higher spectral efficiency and its flexibility to provide both voice and data services for ATS, VDL-3 has been selected by ICAO as the VHF ATS communication system for both voice and data for the long term.

In oceanic airspace High Frequency (HF) voice is the primary means of voice communications today. ATS communications are relayed to/from the ATS provider via an HF communications provider such as ARINC. Satellite voice communications links with much better voice quality are becoming available.

5.1.2 Data Systems

The Aircraft Communications Addressing and Reporting System (ACARS) is widely used today for AOC-aircraft communication. The two major ACARS service providers are ARINC (Aeronautical Radio, Inc.) and SITA (Société Internationale de Télécommunications Aéronautiques). Mobile data link communications are provided over VHF data link, Inmarsat satellite links, and High Frequency Data Link (HFDL). The latter modes provide for communication over the oceans and in remote regions. Ten 25 kHz aeronautical VHF channels are allocated worldwide for ACARS, but in no one location are all ten utilized.

ACARS is a character-oriented set of protocols originally intended primarily to transfer text messages between the AOC and the cockpit. Its usage has subsequently been extended to support communications with the cabin crew (e.g., gate assignments), automatic readout of flight management system (FMS) data, uplink of flight plan data to the FMS and general bit-oriented data transfer over the character-oriented protocols. ACARS is also used to transmit non-time-critical ATS messages, such as pre-departure clearances, meteorological data, digital ATIS (Automatic Terminal Information Service), oceanic clearances and Terminal Weather Information for Pilots (TWIP). The FANS-1 equipment package developed for Boeing aircraft uses ACARS messages to provide Controller-Pilot Data Link Communications (CPDLC) and Automatic Dependent Surveillance-Addressed (ADS-A). ADS-A, also called ADS-Contract (ADS-C) involves the ground ATC system requesting the aircraft to report its position as determined from its own navigation system. This may involve a single position report or the establishment of a contract to report position periodically according to various criteria. A similar package called FANS-A has more recently become available for Airbus aircraft. The term FANS-1/A is used to refer to the general capability, and depending on context may refer to the overall communications system, the specific airborne equipment, or the ATS message formats and protocols. FANS-1/A is widely used for ATS communications in oceanic regions, particularly the Pacific and Indian Oceans, and in other remote areas.

ACARS is specified by ARINC standards, but not ICAO Standards and Recommended Practices (SARPs). Instead, ICAO has developed SARPs for the Aeronautical Telecommunication Network (ATN). This is a bit-oriented set of protocols based on the International Organization for Standardization (ISO) Open System Interconnection (OSI) reference model. The ATN is intended to support both ground-ground and air-ground data communications and allows arbitrary network topology based on packet routing. However, this generality leads to some complexity, requires ATN routers as part of the avionics package, and requires special adaptation layers to make the ATN protocols more bit-efficient for use over low data rate aeronautical mobile data links. ATN protocols support only point-to-point communications, while some proposed aeronautical data link services are more efficiently implemented using broadcast or multicast addressing. Like FANS-1/A, ATN provides application-layer protocols for CPDLC and ADS-A.

However, although capable of supporting AOC communications, specific message formats have not been defined for that purpose. The major effort on ATN has gone into meeting the needs of ATS service providers. Although a great deal of effort has gone into developing ATN standards and implementations, these are currently available only in trial form, and are proceeding slowly toward operational deployment. The FAA expects to support ATN communications at a trial site (Miami) within the next few years, and this is to be coordinated with oceanic and European ATN capabilities to permit transoceanic demonstrations.

ACARS' 2400 bps data rate is regarded as inadequate for today's AOC needs by many airlines and a replacement link called VHF Digital Link Mode 2 (or VDL-2) is currently being implemented. ICAO has approved and published the VDL-2 SARPs. VDL-2 is a 31,500 bps bit-oriented link that is compatible with ATN, and the intended evolution is from ACARS messages over the ACARS link, to ACARS messages over the VDL-2 link, to ATN messages over the VDL-2 link. VDL-2 is also the basis for the distribution of weather data by two FIS-B vendors operating under contract to FAA.

However, given the slow deployment of ATN, the existing FANS-1/A deployment of CPDLC and ADS-A services, the rapid evolution of commercial telecommunications, including mobile communications, and the greater success of the TCP/IP protocol suite compared to the ISO/OSI protocol suite, the future of ATN is uncertain. Competitive pressures from either FANS-1/A or future commercial mobile data services, and benefit/cost analyses by the airlines and ATS service providers, may prevent its widespread operational deployment.

Neither ACARS nor VDL-2 are capable of guaranteeing short messages delays, and so can only be used for ATS messages that are not time critical. The VDL-3 protocol being developed by the FAA for voice and data communication will be able to support such time-critical messages. It uses the same 31,500 bps modulation as VDL-2, but uses a Time-Division Multiple Access (TDMA) protocol for access to the channel rather than the Carrier-Sense Multiple Access (CSMA) protocol used by ACARS and VDL-2, thus guaranteeing channel access within a defined time. It is also a bit-oriented protocol compatible with ATN and an ICAO SARPs is under development.

Yet another VHF digital link using TDMA technology has been proposed by Swedish ATC authorities, and is referred to as VDL Mode 4 in ICAO. VDL-4 is an outgrowth of earlier work done on a self-organizing TDMA (STDMA) system. Currently, VDL-4 is being considered within ICAO only for Automatic Dependent Surveillance-Broadcast (ADS-B), although it is potentially capable of supporting general data link functions including the ATN. With ADS-B, the aircraft position is reported to the ground ATC environment and to other aircraft for situational awareness. This would be a new function for the existing VHF band to accommodate, and it would necessitate dedication of two 25 kHz channels worldwide and additional local channels in areas of high-traffic density. The "self-organizing" feature of VDL-4 has been designed to allow aircraft to determine their own TDMA slot assignments without the need for channel management by a ground station. This concept would allow VDL-4 operation in areas where ground station support is not available, making the system useful in remote areas of the world and in underdeveloped nations. However, high-density airspace requires a higher reporting rate than does remote airspace, therefore additional channels will be needed in terminal areas, along with ground stations to assign aircraft to channels and to set the rate at which aircraft report their position.

VDL-4 is competing with two other proposed means of providing ADS-B service. One is an extension to the Mode S system called the Mode S Extended Squitter. The other is an L-band system called the Universal Access Transceiver (UAT). The use of these systems for ADS-B is described in more detail in Section 5.3.

Mode S is capable of general data link communications. Existing SARPs define the use of the Mode S data link as an ATN-compatible subnetwork. However, there are currently no plans to use Mode S for this purpose. In part, this is due to the timing of the Mode S data link being tied to the rotation rate of the Mode S sensor antenna, although there are potential technical solutions. Another issue is resistance by aircraft operators to Mode S data link equipage. UAT, by design, supports only broadcast data link and is therefore not ATN-compatible. VDL-4 and UAT are still in the process of international standardization.

For the long-term future, a French proposal called "Enhanced TDMA," or E-TDMA, is being discussed but is not officially under study by ICAO at this time.

Table 2 shows the alternative communication systems being proposed for implementation and the type of services each is intended to provide. ATS Messages refers to CPDLC, ADS-A and Flight Information Services. ACARS users, including AOC communications, are expected to transition to VDL-2. VDL-2 will be used for ATS data communication in Europe and the U.S., although the U.S. plans to migrate to VDL-3 when it becomes available. European voice traffic will migrate from 25 kHz voice to 8.33 kHz voice, while the U.S. expects to migrate to VDL-3. Currently there are no plans to use VDL-3 for AOC communication, although that is technically possible. Mode S, VDL-4, and UAT are being considered for ADS-B services.

Table 2. Communication Functions Associated With Current and Future Data Systems

	25 kHz Voice	8.33 kHz Voice	ACARS	VDL-2	Mode S Data Link	VDL-3	Mode S Ext. Squitter	VDL-4	UAT
Voice	✔	✔				✓			
AOC Msgs			✔	✔					
ATS Msgs			✔	✔	✓	✓			
ADS-B							✓	✓	✓

✔ - current communication functions

✓ - potential communications functions

5.2 Navigation

The current ATM system is supported by an infrastructure of VHF OmniDirectional Range (VOR) transmitters with Distance Measuring Equipment (DME). These VOR "nodes" are connected by low altitude and high altitude airways. Most ATM separation functions are based on aircraft following these airways. Area navigation or RNAV equipment that allows direct point to point (great circle route) navigation is widely available. Most commercial airliners use VOR/DME based RNAV equipment in the U.S. Oceanic flight requires Inertial Navigation Systems (INS). Global Positioning System (GPS) has gained wide acceptance in General Aviation and Business aircraft. Selective availability was recently turned off by the military, which increases accuracy. The limitation to use of direct routing is not due to lack of equipment on the aircraft, it is due to lack of capability of the ATM system to accept widespread direct routing

Most commercial flights use Instrument Landing System (ILS) for precision approach. Non-precision approaches are not widely used except by commuter airlines at smaller airports and General Aviation aircraft. Non-precision GPS approaches are now widely available. Frequency limitations will not support a large increase in additional ILS approaches although most airports served by commercial aircraft now have adequate ILS approaches.

The Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS) are designed to extend GPS capability to support precision approaches from the existing 625 airports to approximately 3,300 airports. Problems with the programs have led to a review by the General Accounting Office that questions the cost benefit and technical feasibility of these programs. Additionally there have been some concerns raised over susceptibility of GPS and WAAS/LAAS to jamming. However, the FAA recently made the WAAS system available for VFR use after testing the system for stability and reliability. WAAS improves the accuracy of GPS to 2 meters horizontally and 3 meters vertically throughout the contiguous U.S. The WAAS system will not be approved for IFR use until more testing is completed by the FAA. Raytheon will operate and test the system.

Cockpit display technology has made great strides in recent years. There are now commercially available color displays available to general aviation aircraft that combine navigation information with available traffic, weather, and terrain data. Navigation data includes moving map displays with stored routes and available navaids. Holding procedures, instrument approach procedures, and standard terminal arrival and departure procedures can be appended to the flight plan information and displayed. Traffic from the Traffic Information Service (TIS) or TCAS can be displayed on the same unit. Weather from weather radar or from commercially available satellite services can be overlaid on the display. Lightning strike data available from on-board units can also be displayed. A topographical data base can be accessed based on GPS supplied position to provide warnings or to provide three-dimensional visual displays of the terrain.

Commercial aircraft and corporate jet aircraft have had Electronic Flight Information Systems (EFIS) for some time.

Cockpit Display of Traffic Information (CDTI) has some human factor issues that need to be resolved but there are no technical roadblocks that require research.

The Federal Radio Navigation Plan [4] delineates policies and plans for the radio navigation services provided in the United States.

5.3 Surveillance

In the near term, surveillance will remain primarily ground-based radar and support both Mode S and Air Traffic Control Radar Beacon System (ATCRBS) equipped aircraft. Longer term will see an increase in Mode S equipped aircraft, but support of ATCRBS-only equipped aircraft will continue. The introduction of Automatic Dependent Surveillance-Broadcast (ADS-B) will increase the geographic areas under surveillance but will not eliminate the need for ground-based radar any time in the near future. The current lack of a defined implementation of ADS-B means that implementation is beyond the next five years. It is assumed that ADS-B will be introduced in areas where benefits can be achieved by individual equipped aircraft such as paired approaches or in areas where all aircraft will first be required to equip such as oceanic.

Future operational concepts that are Centralized Ground-based can be supported by secondary radar, but a shift to operational concepts that employ Coordinated (Ground/Air) or Autonomous (Air) modes of control may require Cockpit Display of Traffic Information (CDTI).

A major future surveillance technology is ADS-B, but the shortfall is in the implementation of ADS-B. There is currently no schedule for implementation of ADS-B. There has been no decision on the technology that will be employed for the link. There are three data media candidates: Mode S Extended Squitter, VDL Mode 4, and Universal Access Transceiver (UAT).

A modification of the short squitter used in Mode S known as Mode S Extended Squitter has been proposed as a candidate link for ADS-B. Mode S Extended Squitter has high channel capacity but there has been some question that Mode S has the range to support all future ATM functions. The FAA has suggested that Mode S Extended Squitter might be an interim system. Recent flight tests have demonstrated that the Mode S Extended Squitter can work at long ranges (up to 200 nautical miles) in the highest of interference environment.

VDL-4, as described above, has a low channel capacity but claims high air/air performance. VDL-4 does not yet have a complete channel management system defined. There is no international agreement on frequency assignments. Channel capacity may require even more frequencies.

Another system being evaluated by the FAA is Universal Access Transceiver (UAT), an L-band broadcast data link. Bandwidth requirements have grown to the point where the bandwidth may be difficult to find.

Minimum Operating Performance Standards (MOPS) have been written for Mode S Extended Squitter. There are efforts under way to write the MOPS for VDL-4 and UAT. Specific CNS requirements for ADS-B are being addressed by the standards groups.

The Traffic Information Service (TIS) is a Mode S specific product that uses ground sensors to detect Mode S aircraft position reports and data link (via Mode S) other aircraft positions to Mode S-equipped aircraft. This is useful for aircraft that are not equipped with an ACAS system.

The Traffic Information Service-Broadcast (TIS-B) is a concept that proposes to use a yet-to-be determined data link to non-Mode S-equipped aircraft to supply the position reports of other aircraft. Latency and accuracy are major concerns in the TIS-B concept.

Ground-based systems that multilaterate on received Mode S squitters to provide surface surveillance with ID have been demonstrated.

Table 3 summarizes the current surveillance and status data by ATM domain. Items above the dotted line are current sources of data. Items below the dotted line are near-term expected implementations. The Flight Information System Broadcast (FIS-B) is discussed under hazardous weather.

Table 3. Current/Near-Term Surveillance Sources

	Aircraft Surveillance	Hazardous Weather Regions/Conditions	Winds
National Flow Management	ETMS	ETMS (NEXRAD composite)	NWS gridded winds
Oceanic ATC	Pilot reports via HF radio Pilot position reports via CPDLC, or ADS-A/C position reports, using FANS-1/A and ACARS in some FIRs	GOES weather satellite	NWS gridded winds
	ADS-A/C using ATN		
En route ATC	Secondary radar Primary radar	ARSR weather channel	NWS gridded winds
	(Most primary radar eliminated)	WARP	WARP
Terminal ATC	Secondary radar Primary radar PRM	TDWR, ASR-9 WSP	Anemometer, ASOS for airport surface winds only
	Runway occupancy times (DROM)	• ITWS, • Wake vortex surveillance system (AVOSS)	ITWS
Tower ATC	Visual, Primary radar (ASDE) DBRITE	• Visual • RVR • Ceilometer • LLWAS	Anemometer, ASOS
	Mode S Multilateration, ADS-B, ATIDS		
Flight Deck	Visual, ACAS/TCAS, TIS via Mode S	• Visual • Airborne weather radar	En route: FMS-derived local wind Terminal: ATIS, Digital ATIS via ACARS, Controller voice communication
	CDTI/ADS-B, TCAS-like active interrogation, TIS-B, Synthetic vision on airport surface	FIS-B	FIS-B
AOC ATC	ETMS	ETMS (NEXRAD composite)	NWS gridded winds

5.4 Hazardous Weather

Accurate timely hazardous weather information from TDWR and ITWS is available at the largest airports but the same fidelity of weather information is not available at most small airports. Commercial aircraft and high-end general aviation aircraft have reliable on-board weather radar but lower-end general aviation aircraft have only lightening detectors or must depend on air traffic control advisories. New controller displays allow display of weather as an overlay but the older radar displays have only rudimentary weather depiction.

Flight Information System-Broadcast (FIS-B) is an automated data link system designed to provide non-control, advisory data, including hazardous weather to pilots. The goal of FIS-B data link systems is to provide weather and other flight advisory information to pilots in a way that will enhance their awareness of the flight situation and enable better strategic decision-making. The information provided through FIS-B will be advisory in nature, and considered non-binding advice and information provided to assist in the safe conduct of a flight. The FAA has made two VHF frequencies utilizing a VDL-2 protocol for FIS-B available nationwide.

Future ATM operational concepts require that all users have access to the best weather information available to ensure agreement on how to best avoid hazardous weather. Decision making is facilitated when aircraft and ground have a common weather database. This will require a data link of the weather available on the ground to all aircraft.

6. RELATIONSHIP BETWEEN FAA/NASA ATM RESEARCH AND CNS NEEDS

This section consists of a high-level overview of Joint Research Project Descriptions (JRPDs) that are listed in the Integrated Plan for Air Traffic Management Research and Technology Development. CNS-related needs that might be driven by this research are discussed.

6.1 Interagency Integrated Product Team Research Projects

Following is a list of areas of research covered in the Joint Research Project Descriptions (JRPDs). Reference numbers beginning with J designate the specific JRPDs that are listed in the Integrated Plan for Air Traffic Management Research and Technology Development for each area. These offer insights into future ATM functions that will require CNS support.

6.2 System Cross-cutting Area

The JRPDs in this area are as follows:

J11 ATM Advanced Concept Studies and Explorations

J12 Human Factors for Evolving Environments

J13 System Performance Assessment and Investment Analysis

J14 ATM Operational, Engineering and Safety Methods and Analysis

J16 Application of Aircraft Capabilities to ATM Advanced Concepts

6.2.1 Description

These JRPDs involve concept exploration, modeling, and analysis activities, rather than development of specific system concepts.

6.2.2 CNS Needs

There are no specific CNS needs yet identified in these JRPDs. J16, the Application of Aircraft Capabilities to ATM Advanced Concepts includes the development of airborne automation tools (e.g. conflict resolution), and flight data and situation displays (e.g. 3-D view of the airspace) to support reduced separation. It is likely this will have a CNS component. As specific new system concepts are articulated, new CNS needs may be identified. Human factors activities may identify communications requirements for specific system concepts.

6.2.3 CNS Shortfalls

There are no specific CNS shortfalls yet identified in these JRPDs.

6.3 Collaborative Decision Making

The JRPDs in this area are:

J21 Collaborative Decision Making

J46 Collaborative Arrival Planning

6.3.1 Description

Collaborative decision making refers to allowing NAS users, generally interpreted to be the airline operations centers, to collaborate with air traffic on strategic and tactical flow management decisions. Specifically, the airline operation centers would like to be able to trade off delays among their own aircraft. For example, the airline operation center might like to designate priority flights that would get minimum routing delays, taking the equivalent delays among their other flights. They would also like to have input on decisions involving alternate routing around severe weather. For example, the airline operation center might choose to divert certain of their flights in order to allow other flights priority routing.

Collaborative decision making requires that the airline operations centers have access to the same traffic and weather information as the Traffic Management Units (TMU) in the Air Route Traffic Control Centers (ARTCCs) and at the Air Traffic Control System Command Center (ATCSCC). This is available today. The ATCSCC receives traffic information from all of the ARTCCs and distributes this track data (with some latency) to the airline operation centers via satellite. What is missing is a system that allows the airline operation centers to input their preferences and the air traffic control system to adapt to those preferences.

Flexibility in rerouting is required. This implies the ability to alter flight plans with greater ease than is possible today. A data link between AOC, the aircraft (aircraft Flight Management System), and ATM is needed with the bandwidth to support this type of data flow. This is likely to be provided by a commercial communications provider rather than a dedicated aviation data link.

A near term effort, collaborative arrival planning, calls for a real-time passive, one-way "repeater" of the Center/TRACON Automation System (CTAS) Traffic Management Advisor (TMA) display to be made available to the airline operations centers. This allows the airlines to view and anticipate arrival sequences and delays. Plans call for the airlines to supply data, such as aircraft weight, to CTAS to improve trajectory modeling. Future collaborative arrival planning efforts call for automation tools that will allow the users (airline operations centers) to request and influence intra-airline arrival characteristics through CTAS.

6.3.2 CNS Needs

The CNS needs to support Collaborative Decision Making are to collect and provide to all participants:

- A common surveillance database of all non-military IFR flights currently airborne. This database may be filtered to provide only specific data to individual users.
- A common flight plan database for all flights that will become airborne during the planning horizon.
- A common weather database showing the current regions of severe weather and other current weather conditions that affect aviation.
- A common database of all flow restrictions, ground holds, and Severe Weather Avoidance Plan (SWAP) programs in effect.
- Projections of future airspace congestion and weather conditions that are developed for planning purposes.
- Any additional planning products developed during the collaborative decision making process.

6.3.3 Current CNS Capabilities

Airline operation centers currently have access to the same traffic and weather information as does the Air Traffic Control System Command Center (ATCSCC) although in many cases AOCs have their own weather sources and forecasts. Traffic data is available through the Enhanced Traffic Management System (ETMS). Surveillance data is collected from each ARTCC into the ETMS central database, then distributed to all participants via ground and satellite networks. ETMS provides various methods for projecting future airspace congestion and traffic loading. Airline operations centers have various sources of weather input as good or better than that available to the FAA. Data taps to TDWRs are generally available from commercial vendors. The airline operation centers now interface with ATC on their strategic flow decisions by voice over the telephone. There does not appear to be any technical challenge to allowing airline operational centers to enter preferences, but those interfaces cannot be defined without a more detailed operational concept. There is currently no operational concept describing how the airline operations centers would interface with CTAS/TMA.

6.3.4 CNS Shortfalls

Information security concerns may need addressing. A review of available weather data may be needed to make sure all participants have access to a common database of the best weather available weather.

6.3.5 Issues

It may not be possible to implement user preferences in traffic flow management until the problems of an inflexible route structure and sector workload are resolved. The innovations required may well generate new CNS requirements. There is no operational concept that describes how ATC will develop or implement algorithms for inclusion of user preferences. Near term efforts to allow user inputs to CTAS may be effective where multiple arrival paths and runway assignments are available. It is not clear what aircraft specific data is needed or how it would be supplied to CTAS.

6.4 Surface Movement System

The Surface Movement System (SMS) concept has research under three JRPDs:

J31 Airport Surface Management Technologies

J34 Surface Communications, Navigation, and Surveillance

J35 Airport Surface Operations Modeling and Analysis

6.4.1 Description

The Surface Movement System (SMS) Concept is designed to introduce automation into surface movement planning and to increase safety through increased situational awareness and prevention of runway incursions. Aircraft using GPS/LAAS and surface moving map displays will independently know where they are on the airport surface. The Tower needs to have high-update-rate accurate position reports, with aircraft ID, for all aircraft on the surface landing or departing. The SMS plan also calls for the automation to receive real time weather data and to have a data link to the aircraft. Presumably, the data link might be used for surface route and air route clearances and possibly direct alerts to the cockpit. Whether or not the same data link can be used depends on the reliability and integrity of the link. Weather can be delivered via broadcast. Clearances will require a two-way link. The FAA has Airport Surface Detection Equipment (ASDE-3) surface radar at major airports and is developing a transponder multilateration system. Software known as Airport Movement Area Safety System (AMASS) tracks ASDE targets and provides controller alerts for some classifications of runway incursions. Integrated Terminal Weather System (ITWS) is installed at major airports and the data provided by ITWS can be made available to SMS.

6.4.2 CNS Needs

An all-weather automated surface system requires accurate position reports of aircraft on the surface and on approach and departure. The position reports must have a high update rate (approximately once per second) to support runway incursion prevention and must provide aircraft ID with the target tracks. Surveillance of ground vehicles on the airport surface is also required. The aircraft must be able to navigate on the airport surface in low visibility and know when an active runway is about to be entered and whether or not it is safe to enter that active runway. Communications between the ground and local controller and the aircraft are necessary for taxi clearances.

6.4.3 Current CNS Capabilities

Currently surveillance and identification of aircraft and vehicles on the airport surface is primarily visual. Airport Surface Detection Equipment (ASDE) primary radar is installed at major airports to assist controllers in low visibility conditions. DBRITE is available in Tower Cabs at major airports to provide final approach surveillance. DBRITE displays a repeated copy of a display in the TRACON. Aircraft navigate visually on the surface with reference to airport surface charts with reference to signage and lights. Aircraft provide self-separation visually on the taxiways and movement area following ground repeated copy of a display in the TRACON. Aircraft navigate visually on the surface with reference to airport surface charts with reference to signage and lights. Aircraft provide self-separation visually on the taxiways and movement area following ground control traffic management clearances. Controllers provide separation assurance on active runways. Voice communications are normally used for Automatic Terminal Information System (ATIS) and for landing, taxi, takeoff and route clearances. An ACARS-based VHF data link is available at some major airports for ATIS and route clearances.

6.4.4 CNS Shortfalls

There is a lack of flight identification capability with ASDE. There are also coverage problems at many airports due to shielding and multi-path from structures. Full ASDE-3 systems are too expensive for smaller airports. Another major shortfall is that ASDE and other electronic means of surveillance are not currently approved for separation. A system that is approved for surface separation is required.

DBRITE requires a connection to an ARTS automation system and may not be available a smaller airports not near an ARTS. It is difficult for aircraft to navigate and perform self-separation on the surface in low visibility. Pilots may be unable to determine when it is unsafe to enter or cross an active runway, or to take-off, due to other aircraft on the runway or about to land, especially in low visibility. This eliminates an important backup to controller-provided separation.

6.4.5 Issues

ASDE cannot supply aircraft ID to SMS and without aircraft ID, the functions that can be provided by SMS are limited. ADS-B-equipped aircraft can report their position on the surface. Mode S Multilateration can provide surface position for all aircraft (including those without ADS-B). All aircraft will need surveillance and CDTI of other aircraft on the surface to meet all of the goals of SMS. Research [2] has shown that ASDE with AMASS cannot prevent a significant portion of the observed runway incursions. A runway status light system that can signal when it is unsafe to enter a runway has been proposed to address this shortcoming.

6.5 Sequence and Flow Optimization in the Terminal Area

These three JRPDs are all concerned with optimizing aircraft sequencing and flow (spacing).

J41 Final Approach Spacing Tool (FAST)

J42 Dynamic Final Approach Spacing

J45 TMA Adaptation/Implementation in Complex Airspace

6.5.1 Description

Active Final Approach Spacing Tool (aFAST) provides heading and speed advisories to arrival controllers in order to achieve efficient, conflict free trajectories during vectors from the arrival gates to the final approach fixes. These advisories are in addition to the sequence number and runway assignment provided by passive FAST (pFAST). The goal of aFAST is to provide aids that help the controllers minimize the variance in spacing from the required separation standards.

The objective of the Dynamic Final Approach Spacing program is to reduce in-trail separation requirements by dynamically evaluating factors affecting wake vortex persistence and runway occupancy time. The Aircraft Vortex-Spacing System (AVOSS) will provide dynamic separation requirements based on vortex persistence predictions validated by sensor measurements and the Dynamic Runway Occupancy Management (DROM) system is designed to determine a lower bound on separation requirements based on runway occupancy time.

There is also a research program concerned with adapting the Traffic Management Advisor (TMA) to complex multi-facility airspace such as in the northeast. The TMA is a component of the Center/TRACON Automation System (CTAS) that optimally schedules arrival from en route airspace to the arrival gates and runways. Another component of CTAS, the Descent Advisor (DA), working together with TMA, provides optimum fuel efficient conflict free descents from cruise altitude.

6.5.2 CNS Needs

These programs need accurate low-latency aircraft surveillance in the en route airspace and TRACON. Coverage of all arrival aircraft within 30 minutes of arrival is needed for complete planning. Wind field data is needed with sufficient accuracy to support trajectory predictions. Current and forecast severe weather locations is needed that support the predictions of gate and route closures and openings with accuracy on the order of minutes and forecasts out to thirty minutes. Surface winds and weather front forecasts are needed to support changes in airport configuration (landing runways in use) up to thirty minutes in advance. This is required for TMA sequencing and planning. Surface surveillance is needed that will support runway occupancy time predictions and prevent runway incursions. Surface surveillance is also needed to support integrated arrival/departure planning. A system for wake vortex monitoring/surveillance on the surface and final approach is needed to support dynamic reduction in wake vortex separation standards.

6.5.3 Current CNS Capabilities

Secondary radar surveillance is available for aircraft in the en route airspace and TRACON. Some smaller satellite airports may not have surveillance available in the airport area and currently rely on procedural separation, i.e. blocks of airspace are cleared for one aircraft at a time and release of that airspace depends on pilot reports of position.

Surface surveillance is primarily visual with support from ASDE-3 at major airports.

Wind field data is available from the National Weather Service but the resolution and latency are not sufficient to support accurate trajectory predictions.

Terminal Doppler Weather Radar (TDWR) and Integrated Terminal Weather System (ITWS) are available at major airports, but not at most satellite airports.

6.5.4 CNS Shortfalls

High update rate, very accurate airborne and surface surveillance is needed to support trajectory predictions and runway occupancy predictions at major and satellite airports. Insufficient information on the terminal/surface decision support tools is available to quantify the surveillance requirements. Highly accurate wind field predictions are needed to support TMA planning. Accurate ITWS forecasts of airport, route and gate closures thirty minutes in advance is needed for TMA planning. ITWS and TDWR are not available at most satellite airports.

There is no surveillance capability available to accurately track wake vortices in approach airspace. Some prototype systems are being tested for measuring vortices near the surface.

6.5.5 Issues

One issue is the need to determine the surveillance requirements to support the Decision Support Tools (DSTs). This includes the requirements for surveillance, accuracy, latency, coverage, and data content. Additional work needs to be done to determine the surveillance needs in order for the DSTs to work properly.

The major driving limitation in terminal sequencing and spacing optimization is the lack of a wake vortex surveillance system to allow reductions in wake vortex separation. Studies are needed to determine how much spacing reduction might be possible. There are several prototype sensors being tested but they are generally limited to short final or on the airport. This may prove most beneficial for a reduction in departure spacing. Another approach is to develop predictive algorithms that can determine under what weather conditions wake vortices present a hazard.

6.6 Parallel Runway Spacing Reduction

This JRPD was treated separately because of the unique CNS needs.

J43 Parallel Runway Spacing Reduction

6.6.1 Description

The objective of the parallel runway spacing reduction program is to develop flight deck based situational awareness tools that will allow independent parallel runway operations to runways spaced more closely than the current standard. The concept calls for providing flight crews with information to allow them to assume self-separation responsibility. Current systems call for accurate surveillance with high update rates and dedicated controllers to provide sufficient time to detect blunders and alert the other aircraft to take evasive action. More closely-spaced parallel approach safety is not based on alert timing but on the relative position staggering to avoid the potential for a collision. The parallel trailing aircraft must maintain a position far enough behind the lead aircraft that a blunder would not lead to a collision but close enough to avoid the wake vortex that might be transported over from the lead aircraft.

6.6.2 CNS Needs

The aircraft must be able to navigate precisely along the final approach course for a far as ten miles from the runway. This is required to assure proper lateral position of the paired aircraft to avoid wake vortex encounter. Under certain weather conditions wake vortices will bounce, even in the air. Normal ILS accuracy distant from the runway exacerbates the wake vortex avoidance problem for closely-spaced parallel approaches. Aircraft to aircraft surveillance is needed to allow pilots to assume self-separation responsibility. Some capability to provide the trail aircraft with information on how to be sure of preventing a wake vortex encounter is needed. Reliable communications between the aircraft and between the aircraft and ground is needed.

6.6.3 Current CNS Capabilities

The Instrument Landing System (ILS) is used for precision approaches. Independent parallel approaches are approved only if the runways are separated by at least 9000 feet or if the airport has a final monitor position. If not, the aircraft on the parallel approaches must be staggered to have a 2-mile diagonal separation for runways separated by between 4300 and 9000 feet and a 1.5-mile diagonal separation for runways separated between 2500 and 4300 feet. Airports with an ASR and a final monitor position can conduct independent parallel approaches to runways spaced as closely as 4300 feet. With high update radar and automated alerting, airports with Precision Runway Monitoring (PRM) systems can conduct independent parallel approaches to runways separated by 3400 feet. Self-separation responsibility for parallel approaches is only assumed under visual conditions. There is a minimum separation requirement for distance between runways of 750 feet for operations under visual conditions.

6.6.4 CNS Shortfalls

ILS accuracy out at distances beyond a few miles is not sufficient for independent closely-spaced parallel approaches under instrument meteorological conditions. This will require GPS/LAAS, which is not yet implemented. Curved or offset approaches are also under consideration. Self-separation will require ADS-B with CDTI. TCAS is not designed for this application and will, as a minimum, require logic modification. Without this, it would generate inappropriate alerts. Its current display is not suitable for monitoring closely-spaced aircraft. Efficient initial pairing of aircraft may require greater surveillance accuracy from approach radars or that both aircraft be ADS-B equipped and that the ground be equipped for ADS-B position reports.

6.6.5 Issues

The major issue is whether it is possible to fly safely in a relative geometry that prevents collision potential and avoids the lead aircraft wake vortex. It has not been determined yet whether the approaches will be flown parallel for the entire final approach path or will have one of the approach paths offset up to three degrees. Another issue is that currently certified Flight Management Systems (FMS) are designed to intercept and capture the localizer. FMS have not yet been developed or certified to capture and track the final approach path far from the runway with the precision required to support parallel approaches.

It may be possible to pair a non-equipped aircraft with an ADS-B equipped aircraft and use ground-based surveillance to provide data to the equipped aircraft. Aircraft data link with aircraft intent may be required. This may require a link to the FMS.

6.7 Conflict Prediction and Resolution

There are eight research programs in this area:

J47 RNAV Terminal Routing

J48 Arrival/Departure Management Integration

J51 Controller Capabilities to Manage Traffic in Transition Airspace

J54 Controller Capabilities for Improved Problem Prediction

J55 Controller Capabilities for Improved Problem Resolution

J56 Integration with Other Technologies and Domains

J57 Other Initiatives to Enhance Decision Support Systems

J58 Integration and Application of Decision Support Tools at Sectors

6.7.1 Description

The common CNS element among all of these projects is the need for accurate aircraft trajectory generation in order to predict conflicts and provide conflict resolutions. Conflict resolution alternatives include alternate routing, speed control, altitude change, and vectors. Conflict detection and resolution with a ground-based system may require a data link with the aircraft and/or aircraft Flight Management System (FMS) to accurately predict the trajectory based on aircraft intent. There is a trade-off between look-ahead time, false alerts, and degree of resolution action required.

These projects are in support of Free Flight Phase 1 but are based on an operational concept of a ground-based trajectory generator, conflict detection algorithms, and decision support tools for ground-based direction for conflict resolution. There are other operational concepts for Free Flight that are based on aircraft self separation. These include concepts based on aircraft self-separation using Cockpit Display of Traffic Information with the ground issuing traffic directions. Other concepts depend on trajectory generation based on aircraft intent for a conflict free routing but allow the aircraft to query the ground-based automation through data link for alternate routings. Some concepts employ ADS-B for airborne limitations for aircraft trajectories, that is the flight crew is allowed to deviate without clearance as long as it does not create a conflict and the directions and altitudes that are not conflict free are computed by the aircraft.

6.7.2 CNS Needs

Accurate conflict prediction and resolution that is capable of supporting future ATM operational concepts will require a common database of fused surveillance data from en route airspace, multiple TRACONs and the surface. The assumption is that most aircraft will have RNAV capability. Accurate trajectory predictions out to twenty-thirty minutes will require that the planned (FMS stored) route be available and those changes in trajectory (aircraft intent) are available by data link. Accurate wind field data and a common database of hazardous weather will also be required.

Flight planning data for expected departures will be needed within the planning horizon.

There needs to be a method of interfacing with the flow control situation, both en route and terminal. That is, trajectory generation programs need to anticipate flow control restrictions.

Flight information from the AOCs such as landing weights is needed for planning on arrival and landing speeds.

6.7.3 Current CNS Capabilities

Most commercial aircraft now have RNAV capabilities with FMS and the percentage of aircraft so equipped will increase. ETMS supplies surveillance data from all of the ARTCCs but the update rate is on the order of minutes. Filed flight plans are available for predicting departures. Wind field data is available from the National Weather Service but it is not clear that the resolution and update rate is sufficient to support the required accuracy of trajectory prediction. These requirements need to be defined. In some instances company aircraft FMS data can be downloaded by AOCs, but this data is not normally available to ATM and it the data link is not yet in place to support aircraft intent information being fed into trajectory prediction programs. Communications between aircraft and ATM is limited to voice within a sector.

6.7.4 CNS Shortfalls

The ETMS data is not sufficient to support the trajectory generation, conflict prediction, and conflict resolutions envisioned in future ATM operational concepts. The latency is too large, there is no system for merging surveillance data from multiple TRACONs and from the surface. Adequate data for planned departures is not available. The procedures for integrating flow control restrictions into trajectory prediction algorithms are still being developed and tested.

6.7.5 Issues

The assumption is that initial ATM operational concepts will rely on ground-based trajectory generation and conflict detection and resolution. Research is underway on ground-based conflict probes but planned departures need to be integrated into the system. An operational concept for airborne conflict detection and resolution independent of TCAS is not yet in place. The trade-off between conflict detection and false alerts will most likely require that the ground-based system have a direct data link to the aircraft in order to predict the trajectory with the required look-ahead time and accuracy. It is not clear what aircraft intent information is necessary to support these ATM operational concepts. For instance, will it be necessary to have a dynamic data link to the aircraft's FMS or will trend vector data from the aircraft be sufficient. Dynamic flow control restrictions need to be included in trajectory generation. Requirements for windfield data need to be determined.

6.8 Oceanic

There are two JRPDs listed under Oceanic:

J61 Oceanic Automation for a Common ARTCC Infrastructure

J62 Oceanic Separation Standards

6.8.1 Description

Oceanic Automation for a Common ARTCC Infrastructure is concerned solely with tools to increase controller productivity through the application of existing technology that would allow shared responsibility between controllers in a sector and the elimination of flight progress strips. There are no special CNS requirements generated by these JRPDs.

Oceanic Separation Standards is concerned with reducing separation standards in all three dimensions over the Pacific and Atlantic. Current use of HF radio for position updates is unacceptable. The plan calls for limited transition of separation assurance responsibility to the cockpit. Currently TCAS is used in a limited way to allow over water overtakes. Since TCAS is supposed to remain an independent safety assurance system and since a bigger role is envisioned for Cockpit Display of Traffic Information, it will require an ADS-B system to achieve these reductions.

6.8.2 CNS Needs

The CNS needs for future oceanic ATM operations include accurate reliable navigation for all aircraft. Surveillance of oceanic aircraft is necessary to ensure conformance to flight plan routes and separation assurance. Future operational concepts envision a transfer of separation responsibility to the aircraft based on airborne surveillance. A common accurate database of hazardous weather in oceanic airspace is needed.

6.8.3 Current CNS Capabilities

Aircraft in oceanic airspace now navigate using Inertial Navigation Systems (INS). Three operating independent units are required for dispatch. Route structures take into account cumulative errors in INS and allow for drift-down areas in case of an engine failure. Surveillance is through position reports over HF radio. Controller-pilot communications are also over HF radio. There is some limited use of FANS-1 data link for ADS-A and communications of clearances as described in Section 5.1.2. TCAS is used for air-to-air surveillance. There is partial coverage by weather satellite systems.

6.8.4 CNS Shortfalls

INS-only navigation accuracy is probably not sufficient to support future ATM oceanic operational concepts. However, INS integrated with GPS should provide the accuracy and reliability needed. ADS-B and CDTI are needed for self-separation responsibilities, TCAS should remain an independent safety system. Weather data is marginal and incomplete.

6.9 Summary of CNSW Capabilities and JRPDs

Table 4 summarizes the current, limited deployment, and needed/proposed Communications, Navigation, Surveillance, Weather (CNSW) capabilities with the JRPDs. After reviewing the future ATC operational concepts, it became clear that weather needed to be treated on an equal basis with communications, navigation, and surveillance. A check mark indicates that the JRPD uses that capability or is in the process of developing that capability. A question mark indicates uncertainty as to whether that capability will be used or developed.

For the most part the JRPDs depend only on current or near-term CNS operational capabilities, although additional ATM capabilities and performance improvements might result from new or improved CNS capabilities. The primary exception is the Surface ATM domain, which currently has no suitable surveillance system available to support automated decision support tools. Work in this area is dependent on creation of a surface surveillance capability.

Table 4. CNSW Capabilities Addressed by JRPDs

Current CNSW Capabilities	Traffic Flow Management Area	J21: Collaborative Decision Making	Surface Area	J 31: Airport Surface Management Technologies	J34: SMS Communication, Navigation and Surveillance (CNS)	J35: Airport Surface Operations Modeling and Analysis	Terminal Area	J41: Final Approach Spacing Tool	J42: Dynamic Final Approach Spacing	J43: Parallel Runway Spacing Reduction	J45: TMA Adaptation/Implementation in Complex Airspace	J46: Collaborative Arrival Planning	J47: RNAV Terminal Routing	J48: Arrival/Departure Management Integration	En Route Area	J51: Controller Capabilities to Manage Traffic in Transition Airspace	J54: Controller Capabilities for Improved Problem Prediction	J55: Controller Capabilities for Improved Problem Resolution	J56: Integration with Other Technologies and Domains	J57: Other Initiatives to Enhance Decision Support Systems	J58: Integration and Application of Decision Support Tools at Sector	Oceanic Area	J61: Oceanic Automation for a Common ARTCC Infrastructure	J62: Oceanic Separation Standards
Surveillance	TFM		Surface				Terminal								En Route							Oceanic		
NAS-wide aircraft surveillance database (ETMS)		✓																						
En route aircraft surveillance (radar position, reported altitude, derived velocity and altitude rate, reported identity)		✓						✓			✓	✓		✓		✓	✓	✓						
TRACON aircraft surveillance (radar position, reported altitude, derived velocity and altitude rate, reported identity)								✓			✓	✓	✓	✓										
Airport surface surveillance of aircraft and ground vehicles (ASDE, primary radar position only, not available to automation systems)																								
Oceanic surveillance of aircraft (pilot-reported position, altitude and identity via voice radio; flight plan velocity)																								
Pilot position reports via Controller-Pilot Data Link Communication (CPDLC) using FANS-1/A and ACARS in some flight information regions																								
ACAS/TCAS air-air surveillance																							✓	✓
Navigation	TFM		Surface				Terminal								En Route							Oceanic		
VOR/DME																								
RNAV											✓		✓											
ILS																								
NDB																								
TACAN																								
Loran-C																								
Inertial																								
Communication	TFM		Surface				Terminal								En Route							Oceanic		
NAS-wide flight plan database (ETMS)		✓																						
NAS-wide database of flow restrictions, ground holds, Severe Weather Avoidance Plans (SWAPs)		✓																						
Intent/plan communicated by filed flight plan and amendments as approved by ATC		✓						✓			✓			✓		✓	✓	✓						
Controller/pilot communications via voice radio								✓			✓		✓	✓		✓	✓	✓						
Pre-departure clearances and ATIS via ACARS data link at many major airports																								
Terminal Weather Information for Pilots (TWIP) via ACARS at airports with TDWR																								
ACAS/TCAS air-air maneuver coordination																								
Weather	TFM		Surface				Terminal								En Route							Oceanic		
General: National Weather Service gridded winds		✓						✓			✓	✓		✓		✓	✓	✓						
NAS-wide hazardous weather regions		✓																						
En route: ARSR weather channel available to controllers but not to automation																								
Terminal: TDWR, ASR-9 WSP, ASOS, LLWAS																								
Surface: local wind, runway visibility and ceiling. ASOS, LLWAS, TDWR																								
Oceanic: GOES weather satellite																								

Current CNSW capabilities in deployment/equippage	TFM	Surface			Terminal							En Route						Oceanic	
Precise, frequently updated surveillance of aircraft on parallel approach paths (PRM)																			
MLS (26 units)																			
GNSS/GPS		✓	✓															✓	✓
Traffic Information Service (TIS) via Mode S																			
Needed/Proposed CNSW Capabilities (Proposed Systems)																			
Surveillance	TFM	Surface			Terminal							En Route						Oceanic	
Surveillance of aircraft on final approach, with identity		✓	✓																
Precise surveillance of aircraft and ground vehicles on or near surface, with identity (ADS-B, ATIDS multilateration)		✓	✓								✓								
Air-air surveillance for airborne self-separation on closely-spaced parallel approaches (ADS-B, TCAS-like active surveillance)							✓												
Air-air surveillance for general airborne self-separation (ADS-B, TCAS-like active surveillance)																			✓
Automatic Dependent Surveillance -Addressed (ADS-A)	?																	✓	✓
Synthetic vision or other techniques for aircraft self-separation on the airport surface in low visibility		✓	✓																
Measurement of runway occupancy times (DROM)						✓													
Navigation	TFM	Surface			Terminal							En Route						Oceanic	
Enhanced GPS precision and reliability/integrity monitoring in the airport vicinity and on the surface (LAAS)		✓	✓																
Enhanced GPS precision and reliability/integrity monitoring throughout the NAS (WAAS)																			
Improved lateral navigation on final approach (GPS/LAAS)							✓												
Better integration of GPS and INS for improved accuracy and reliability																			
Navigation on airport surface in low visibility		✓	✓																
Communication	TFM	Surface			Terminal							En Route						Oceanic	
ATN-compliant Controller Pilot Data Link Communication (CPDLC) via VDL-2		✓	✓												✓				
ATN-compliant Controller Pilot Data Link Communication (CPDLC) via Satellite																		✓	✓
Integrated voice/data communications for time-critical CPDLC (NEXCOM/VDL-3)		✓	✓												✓				
AOC information: pre-departure weight, engine information, for improved trajectory prediction									✓						✓				
AOC arrival preferences for their aircraft									✓										
Provide CTAS terminal area information to AOCs									✓										
Ground readout of aircraft state/status information (Mode S GICB combined with ASTERIX ground communications)															✓				
Air-air communication for airborne self-separation							?												
Ground-to-air communication of hazardous weather regions																			
Pilot involvement in selection of en route problem resolutions														✓					
Automated warnings to pilots to prevent runway incursions (runway status lights, cockpit displays/alerts)																			
Weather	TFM	Surface			Terminal							En Route						Oceanic	
En route: Wind fields (WARP)																✓			
En route: Hazardous weather regions (WARP)											?		✓	✓		✓			
Terminal: Improved wind field (ITWS)					✓	✓													
Terminal: Hazardous weather regions (ITWS)					✓						?								
Terminal: Wake vortex surveillance system (AVOSS)						✓													
Terminal: Nowcasting atmospheric conditions up to 1 hour into future, to support modeling future wake vortex persistence and transport (ITWS?)						✓													

7. IDENTIFIED CNS ISSUES

This section summarizes the issues that arise with regard to the ability of CNS systems to support the decision support tools expected to be produced by current and future research efforts. An issue is defined as a performance/requirement comparison for which a significant question can be asked regarding whether the performance of the CNS systems will be adequate. Section 7.1 introduces some very broad issues that span many areas. Sections 7.2-7.4 discuss communications, navigation, surveillance, and weather issues. Table 5 shows how the key issues fall with regard to CNS area (Surveillance, Navigation, Communication, Weather) and ATM domain (En Route, Terminal, Surface, Oceanic, and System).

7.1 General Issues

The following key issues apply to CNS/ATM implementations in several domains:

7.1.1 Uncertainty in procedures and responsibilities for shared separation assurance

Uncertainty surrounding the procedures and responsibilities for future ATM separation assurance concepts produce uncertainty in defining the associated CNS requirements. Several CNS characteristics, such as surveillance coverage or communication link integrity, are dependent upon the design choices for separation assurance.

7.1.2 Ability to transition equipage

When an innovation is dependent upon aircraft equipage, a transition strategy must be developed that will provide benefits to equipped aircraft early in the transition period. Any system that requires full equipage before benefits are realized is likely to face insurmountable transition obstacles.

7.1.3 Voluntary versus mandated equipage

Currently, system planning appears to be operating under the requirement that equipage with new equipment must be voluntary and not involve a mandate. This can make it impossible to justify desirable long-term capital investments since the prospects for full equipage becomes uncertain. The need to maintain existing support infrastructure indefinitely prevents service providers from obtaining the cost savings that would justify implementing a new, more efficient infrastructure. This difficulty could be addressed by improving institutional processes for making long-term decisions regarding whether to employ mandated or voluntary equipage.

7.2 Communications Issues

Key communications issues are identified below:

7.2.1 Availability of RF Spectrum

VHF voice spectrum is becoming a problem. Europe is going to 8.33 kHz voice spacing to provide additional channels within allocated bands. The proposed VDL-4 and UAT implementations of ADS-B must define an implementation that considers the current limited availability of spectrum. Furthermore, the increasing demand for wireless communication services has led to an effort within the International Telecommunications Union to allow mobile satellite services to use frequencies currently reserved for aircraft navigation. This reallocation was rejected at the June 2000 World Radiocommunication Conference, but the continued growth of the wireless industry could lead to similar proposals in the future. In order to be prepared to defend aviation spectrum, the requirements for future ATM concepts should be carefully documented.

7.2.2 Selection of data link implementation

The data link implementation for NAS-wide use has not yet been determined. Planned deployment is very lengthy. It may be that continued rapid development of commercial mobile broadband links will lead users to view ATC-specific links as obsolete and no longer viable. If investment in ATC-specific links falters, DSTs may have to transition to new links with new characteristics.

7.2.3 Information security

Information security issues that are introduced by future ATM operational concepts have not been widely studied. Data link functions may be vulnerable to attack. ADS-B links may prove easy to spoof. Flight deck nets may have potential interconnections with other onboard nets (e.g. passenger nets) that could expose them to attack.

7.2.4 Reliability for self separation

Little work has been done to define the communications requirements that need to be developed to support distributed air-ground separation responsibilities beyond the development of ADS-B. Some of the potential complexities that can arise in even simple air-to-air applications can be inferred from the extensive work required to develop TCAS/TCAS coordination.

7.2.5 Latency for separation functions

Some data link implementations introduce a variable delay (latency) into the communication process. This can be caused by capacity problems when sharing the channel with other users, by varying routing of data through the network, or by the need for retransmission in the event of link failures. For separation functions, the latency requirements can be stringent and may not be satisfied to the required confidence by all data link implementations.

7.2.6 Downlink content for distributed control

Provision must be made for the downlinking (cross-linking) of onboard data for distributed control and autonomous functions. The issue arises not only from the requirement that data be provided from onboard systems, but also from requirements that such data must be guaranteed to be valid and be updated within a given time period when it changes.

7.2.7 Downlinked data for closely-spaced arrivals

Concepts involving closely-spaced arrivals or paired approaches may require that additional onboard data be provided to either other airborne aircraft or to the approach monitoring DST. Information that might be needed include aircraft weight, speed profiles, FMS guidance mode/status, bank angle, etc.

7.2.8 Cost/benefit of data link communications

AOC-to-aircraft data link communications is clearly beneficial since the airlines have implemented this at their own cost and are upgrading the system. The benefits of ATC-to-aircraft data link are clear in oceanic and remote airspace. The case is less clear for ATC data link in domestic airspace, and this could delay equipage or lead to equipage with data link implementations that do not fully serve ATM needs..

7.3 Navigation Issues

Key navigation issues are identified below:

7.3.1 Integrity and Security of GPS

For safety-critical functions, GPS must demonstrate adequate integrity and security. The GPS modernization program will reduce GPS susceptibility to intentional jamming. The issue is whether GPS can be the sole means of navigation in the NAS. If not, then plans for a secondary system(s) need to be defined.

7.3.2 Accuracy of GPS navigation during paired approaches

Paired approach concepts rely on precise interaircraft spacing on final approach. ILS cannot support this accuracy at the distance at which pairing first occurs. GPS/WAAS has the necessary navigation accuracy, however, current aircraft Flight Management Systems that can capture the flight path and track to the desired precision during all of the final approach have not yet been developed or certified.

7.3.3 Availability and integrity of position on surface

Under low visibility conditions when advanced surface management systems are in use, there may be a need for the aircraft to be better aware of its own position with regard to runways and taxiways. This can be viewed as a question of CNS support for navigation on the airport surface when visual navigation is inadequate.

7.4 Surveillance Issues

Key surveillance issues are identified below:

7.4.1 Schedule for ADS-B implementation

There are competing ADS-B technologies and there is no firm schedule for ADS-B implementation. Some near-term ADS-B implementations could be delayed by lack of agreement on implementation specifics.

7.4.2 Integrity and Security of ADS-B for primary safety functions

The use of ADS-B for airborne self-separation raises issues concerning data integrity, the need to protect against spoofing, and the need for independent validation by other surveillance modes.

7.4.3 Common surveillance database among facilities

ATM functions that operate over long distances or require agreement between modules at different facilities may require that a common surveillance database be utilized. For example, intersector coordination of conflict detection and resolution may require that there be agreement on whether a conflict exists and what trajectory change is required to resolve it. Achieving a common database implies a more complete sharing of data among facilities. This will require significant modifications to current automation systems as well as provision of adequate communication bandwidth.

7.4.4 Availability of adequate surface surveillance

Future surface management systems will provide efficient control of congestion on the airport surface and will provide efficient integration of arrivals and departures. In order to achieve envisioned efficiencies, the systems must know the positions and identities of aircraft on the airport surface. Questions arise concerning 1) locations on the airport surface where propagation is obstructed by buildings, 2) vehicles (aircraft and surface vehicles) that may not be equipped with transponders or ADS-B, and 3) capabilities of Mode S multilateration systems.

7.4.5 Surveillance requirements needed to support Decision Support Tools

Work needs to be done to determine the surveillance needs in order for the DSTs to work properly. This includes determining surveillance accuracy, latency, coverage, and data content requirements.

7.5 Weather Issues

Key weather issues are identified below:

7.5.1 Accuracy and availability of hazardous weather forecasts

Some future ATC concepts require accurate forecasts of hazardous weather to plan aircraft routing and optimize traffic flow. The accuracy of such forecasts for times more than 30 minutes into the future is an issue. How this data will be made available to all users must be determined. Decision support tools will require modifications to use this weather data.

7.5.2 Accuracy of wind field data

More accurate, higher resolution en route, terminal, and oceanic wind field data is needed to support future ATC automation concepts.

7.5.3 Accuracy of wake vortex hazard measurements

More accurate, higher resolution wake vortex measurements are required to support capacity enhancing concepts in the terminal area, for both arrivals and departures. Accurate forecasts of wake dissipation times for planning purposes will be required for dynamic wake vortex spacing.

7.5.4 Accuracy of ceiling and visibility forecasts

Improved airport ceiling and visibility forecasts are needed to forecast airport acceptance rates in support of flow control planning.

Table 5. Key CNS/ATM Issues

ATM DOMAIN

	EN ROUTE	TERMINAL	SURFACE	OCEANIC	SYSTEM (INCLUDING TRAFFIC FLOW MGT.)
GENERAL	7.1.1 Uncertainty in procedures and responsibilities for shared separation assurance	7.1.1 Uncertainty in procedures and responsibilities for shared separation assurance		7.1.1 Uncertainty in procedures and responsibilities for shared separation assurance	7.1.2 Ability to transition equipage 7.1.3 Voluntary versus mandated equipage
COMMUNICATION	7.2.4 Reliability for self separation 7.2.5 Latency for separation functions 7.2.6 Downlink content for distributed control (preferred routing, conflict resolution preference, etc.)	7.2.6 Downlink content for distributed control (especially runway assignment and final approach planning) 7.2.7 Downlinked data for closely-spaced arrivals	7.2.5 Latency for separation functions (runway incursion protection)		7.2.1 Availability of RF Spectrum 7.2.2 Selection of data link implementation 7.2.3 Information security 7.2.8 Cost/benefit of data link communications
NAVIGATION		7.3.2 Reliability and integrity of GPS navigation during paired approaches.	7.3.3 Availability and integrity of position on surface		7.3.1 Integrity and Security of GPS
SURVEILLANCE	7.4.3 Common surveillance database among facilities (to facilitate conflict probing across center boundaries) 7.4.5 Requirements to support Decision Support Tools	7.4.3 Common surveillance database among facilities (Access to surveillance database for all aircraft within required terminal planning horizon) 7.4.5 Requirements to support Decision Support Tools	7.4.4 Availability of adequate surface surveillance		7.4.1 Schedule for ADS-B implementation 7.4.2 Integrity and Security of ADS-B for primary safety function 7.4.3 Common surveillance database among facilities
WEATHER/ WAKE	7.5.1 Accuracy and availability of hazardous weather forecasts (for en route rerouting and flight planning) 7.5.2 Accuracy of wind field data	7.5.1 Accuracy and availability of hazardous weather forecasts (that affect terminal flows) 7.5.2 Accuracy of wind field data 7.5.3 Accuracy of wake vortex hazard measurements (to facilitate dynamic wake vortex spacing) 7.5.4 Accuracy of ceiling and visibility forecasts (to plan arrival flows and runway utilization)	7.5.3 Accuracy of wake vortex hazard measurements (to determine when wake vortices allow departure to proceed)	7.5.1 Accuracy and availability of hazardous weather forecasts (in oceanic airspace).	7.5.1 Accuracy and availability of hazardous weather forecasts (for system-wide capacity forecasting)

8. CONCLUSION

This study has identified a number of areas in which CNS capabilities are critical to advanced ATM concepts that are the subject of current research within the Interagency ATM Integrated Product Team (IAIPT). The bulk of current IAIPT research is focused upon near-term products that use existing CNS systems. These products are adapted for current CNS capabilities and few CNS/ATM issues are unresolved for them. The primary exception is the work on surface systems for which adequate surveillance systems are just being developed. But when more advanced research is considered (for products that may not appear for 5-10 years or more) a number of issues arise. When CNS requirements of ATM are not explicitly defined, CNS system planners have difficulty finding a basis for specification of such critical CNS attributes as integrity, reliability, and security. In some instances, such as the need to defend aviation spectrum against encroachment by commercial wireless services, an inability to document far-term CNS needs can lead to significant loss of future benefits. For these reasons, it is recommended that ATM research IPTs give explicit attention to far-term CNS requirements and engage in a continuing dialogue with CNS developers and planners regarding these requirements.

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