CO-OPERATIVE AIR TRAFFIC MANAGEMENT: A TECHNOLOGY ENABLED CONCEPT FOR THE NEXT GENERATION AIR TRANSPORTATION SYSTEM

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Abstract

Co-Operative Air Traffic Management (CO-ATM) is a concept under exploration at NASA Ames Research Center for transformation of aircraft and air traffic management operations towards the Next Generation Air Transportation System (NGATS). A goal of the CO-ATM concept is to provide a scalable framework to significantly increase NAS capacity and efficiency while maintaining safety. A second goal of this concept is to provide airspace users with increased flexibility in managing their operations.

CO-ATM envisions sector controllers controlling conventional aircraft along predictable flight paths and area controllers coordinating strategic trajectory changes with flight crews of equipped aircraft in the same airspace via data link. Area controllers operate with extensive automation support for conflict detection and resolution and traffic flow management. Flight path changes are distributed to effected sectors. Routine tasks like handoffs and transfer of communication are conducted by the automation. Equipped aircraft may be cleared to operate at different levels of autonomy. Tasks like aircraft-to-aircraft spacing may be delegated to the flight crews by the controller. Flight crews of equipped aircraft can coordinate preferred trajectories for traffic flow constraints with the area controller or operate at higher levels of autonomy, if desired and authorized.

CO-ATM aims at achieving substantial capacity and efficiency benefits through improved information exchange and changes in roles and responsibilities. It builds on lessons learned from Distributed Air/Ground Traffic Management (DAG-TM) research, and addresses identified safety, coordination, automation and mixed equipage concerns. CO-ATM provides a transition path from the current system to the next generation with gradual shifts in roles and responsibilities and incentives for aircraft operators to equip.

The paper reviews plans and concepts for the NGATS and relevant research findings from DAG-TM studies. It presents the CO-ATM concept in detail and presents a possible transition path in line with ongoing research at NASA Ames, addressing the integration of trajectory based operations and Airborne Separation Assistance Systems (ASAS). This concept is currently in its definition and exploration phase and is in line with research funded in the NextNAS project of NASA's Airspace Systems Program. Based on our previous air/ground integration research we believe that the CO-ATM concept has a number of promising properties and is presented here in its early stages to initiate further discussion, helping us in identifying shortcomings and supporting future development.

Background

The Next Generation Air Transportation System (NGATS)

In December 2004 the Joint Planning and Development Office (JPDO) transmitted the "Integrated National Plan for the Next Generation Air Transportation System" [1] to the United States Congress. The plan stresses the need for a new technology-enabled approach to air transportation. It outlines a high-level vision for 2025 that combines increased automation with new procedures to achieve economic, capacity, safety, environmental, and security benefits. The plan presents a number of operational concept elements that are aimed at tripling sector and airport capacity by 2025. New avionics will enable aircraft to operate with increasing levels of autonomy and increase flight deck situational awareness. Intelligent applications of automation will make new Air Traffic Management (ATM) concepts possible including shared or distributed separation management. ATM operations are envisioned to rely on end-to-end strategic traffic flow management, data link communication and information sharing to facilitate quiet and fuel efficient flight profiles coordinated between ground automation and airborne flight management systems while minimizing adverse weather effects.

The JPDO identifies 8 transformation strategies with key research areas. The research presented in this paper is in line with the applicable strategies and specifically addresses the first key research area for the strategy to *Establish an Agile Air Traffic System*: "Conduct research to evaluate alternative allocations of air traffic management services and functions between the ground and the air, and the automation and the human, to address critical system attributes such as capacity, agility, cost, human factors, reliability, safety, performance, and transition paths."[1]

Far-Term Concepts

Visions for tripling capacity in 2025 rely on new automation and procedures to offload tasks from the air traffic controller. One approach is the concept of airborne self-separation (ASAS 4) [2] [3] that allocates air traffic control tasks including separation management to flight crews of appropriately equipped aircraft. Another approach is the advanced airspace system [4] that focuses on the ground automation as the primary means for providing air traffic services with the air traffic controller in a supervisory role. Both these approaches require a highly advanced Communication, Navigation and Surveillance (CNS) infrastructure to exchange 4D trajectories and advanced Decision Support Tools (DST) on the ground side and/or the aircraft for short and medium term conflict detection and resolution. Moreover, a substantial paradigm shift regarding the roles and responsibilities of flight crews, controllers and automation will be necessary to put these concepts into operation.

Current Situation

The current air traffic system, however, is far from ready to support any of these future visions, even though advanced CNS technologies and DSTs are operationally implemented and applications are defined to use these technologies.

Automatic Dependent Surveillance-Broadcast (ADS-B) and Controller Pilot Data Link Communication (CPDLC) are already used in local regions scattered around the world and are expected to be more widely used in the near future. On the ground side ADS-B can enable surveillance applications in areas with no radar coverage and enhance information for controllers and their decision support tools. On the flight deck ADS-B can enable flight crews to use traffic information for enhanced situation awareness and separation assistance tasks. Near-term applications of ADS-B are being defined and fast-tracked through ICAO and the authorities to make immediate use of this technology in the current day environment. Ground-based tools for strategic metering and flow management and airborne automation for more efficient flight path management are developed and implemented in addition to ADS-B and CPDLC enabled technologies.

The CO-ATM concept presented in this paper provides a framework for future air traffic operations enabled by advanced ground-based automation, ASAS and new CNS technologies. Moreover, it addresses how today's various modernization trends can be integrated and aligned along an incrementally beneficial transition path. In the following section we will review some of the research that motivated the development of the CO-ATM concept, then we will explain the concept in detail.

Motivation

Development of the CO-ATM concept is motivated by several factors. Firstly, our extensive recent research on Distributed Air/Ground Traffic Management (DAG-TM) concepts like airborne self-separation, airborne spacing and trajectory negotiation has provided us with more insights on potential capacity, efficiency and safety impacts of the various concept elements. Secondly, our ongoing research on a gradual transformation of the airspace system using Trajectory-Oriented Operations with Limited Delegation (TOOWiLD) indicates a promising approach to integrating the air and the ground systems on a conceptual, procedural and technological level. Thirdly, earlier research on multi sector planning and air/ground integration as well as current trends towards implementing early airborne separation assistance systems (ASAS) may provide a realistic avenue for transforming the airspace system.

DAG-TM research findings

Extensive research on DAG-TM concepts has been conducted at NASA Ames, Langley and Glenn Research Centers. Along with research in Europe, DAG-TM has provided us with insights on potential capacity, efficiency and safety issues and benefits of the various concept elements:

Most strikingly the recent DAG-TM research on *mixed operations with airborne self-separating and controller-managed aircraft* demonstrates a tremendous potential for increasing capacity, if the separation responsibility within a given airspace is split among multiple operators. However, airborne self-separation has raised safety concerns and requires substantial new automation in the air and on the ground. These findings are reviewed in the next section; see DAG-TM reports for a complete review [5 and 6].

The concept of *trajectory negotiation* has been proven to be a non-controversial concept for exchanging efficient 4D trajectories between the air and the ground and may provide substantial, but probably insufficient capacity increases if integrated into the current infrastructure [9]. *Airborne spacing* has also been shown to be an acceptable and feasible concept; delegating well defined tasks to the flight crews [10][11].

Mixed operations with airborne self-separation

A Joint NASA Ames/Langley simulation of mixed operations was conducted in June 2004 [5] [6]. During the simulation free maneuvering (i.e. self-separating) aircraft shared en route and transition airspace with controller-managed aircraft. The analysis of aircraft counts and workload data across four sectors revealed that the sector controller's workload is primarily related to the number of aircraft he or she controls. Many more aircraft may be added to the same airspace if someone else is responsible for their separation. However, controllers reported that as the total number of aircraft increased, their available options for safely managing their traffic decreased. Figure 1 [6] visualizes the relationship between the number of controller-managed flights, free maneuvering aircraft and controller workload for different traffic mixes (Conditions 1-4). In Condition 1 (C1) controllers managed trajectories and separation for all aircraft. In C2-C4 traffic mixes with an increasing number of self separating aircraft were simulated. Workload was measured during the simulations using workload assessment keypads that prompted controllers to rate their workload on a scale of 1 (lowest) to 7 (highest) every five minutes.

In the current day environment the Monitor Alert Parameters (MAP) for these sectors are set such that controllers control less than 20 aircraft at all times. During the simulations with ground automation for handoff and communication changes controllers handled more traffic than today. The workload appeared to be primarily related to the number of managed aircraft in each sector which was held constant, and not to the total sector count which was up to 3x current day traffic levels.

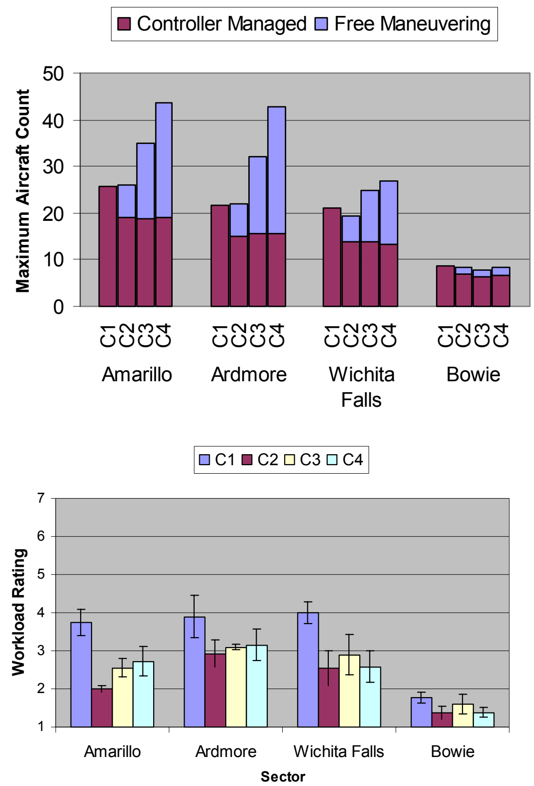

Figure 1: Maximum aircraft count and controller workload for 4 test sectors across 4 conditions (C1-C4) during DAG-TM simulations [6]

The idea of air/ground distributed separation responsibility, however, has raised a number of safety concerns with the controllers - fueling sometimes passionate discussions about its acceptability and the required paradigm shift. The controllers' subjective safety ratings and comments reflect these concerns. Controllers rated mixed operations much less safe than managed operations [5][6]. However, this assessment was based on one particular concept implementation at an early technology readiness level. Therefore, these safety concerns should not be considered a show stopper for the concept of airborne self-separation, but they need to be taken very seriously. More research is required and significant adjustments to the concept of operations need to be made before mixed operations at the high traffic levels simulated during DAG-TM can be realized.

In addition to the safety concerns, airborne self-separation requires a highly developed infrastructure with extensive new air and ground equipage for self-separating and managed aircraft.

It is our opinion that equipping for airborne self-separation should be optional for aircraft operators rather than an ATM requirement to increase capacity. It is therefore desirable to create an environment that can achieve the capacity increase without requiring airborne self-separation. The system should however be designed in a way that autonomous aircraft operations can be authorized and operators can take advantage of the increased flexibility and efficiency provided by new airborne avionics systems.

Co-Operative Air Traffic Management

The concept of CO-ATM described in this paper is designed to achieve capacity and efficiency benefits which will accrue from a distribution of roles and responsibilities and intelligent applications of automation while preserving current levels of safety in a mixed equipage environment. Furthermore, it is intended to provide incentives and benefits for equipped aircraft. CO-ATM is our approach to combine the beneficial properties of distributed separation responsibilities, trajectory negotiation, increased aircraft autonomy and automation assisted separation assurance.

The following sections describe the principles for co-operation and the air/ground infrastructure that is needed to enable CO-ATM operations. Then, CO-ATM ATSP and flight deck operations will be described.

Principles for Co-operation

The CO-ATM concept relies on co-operation between traffic management, controllers and flight crews for managing the increased traffic demand. The envisioned operations combine absolute -4D trajectory-based- and relative -aircraft-to-aircraft spacing- operations. They are in line with research findings and analyses of the air traffic system conducted in Europe and the US proposing the combination of absolute and relative operations [12][13]. Research on trajectory-oriented operations with limited delegation (TOOWiLD) has identified the following principles for co-operation [14]:

Use time-based flow management to regulate traffic density,

Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,

Maintain local spacing between aircraft with airborne separation assistance.

Figure 2 indicates some example time horizons for co-operation between the different entities. Time-based TFM co-operates with airlines for scheduling purposes and to make sure that aircraft arrive at the appropriate time (within a few minutes) at the destination airport arrival sectors. Controllers co-operate with flight crews to further adjust aircraft trajectories so that aircraft can arrive at merge points for their approach routing with only small arrival time errors (e.g. less than 20 seconds). If the aircraft are properly set up for the merge controllers can delegate the task of fine-tuning the inter arrival spacing to the flight crews using airborne spacing procedures.

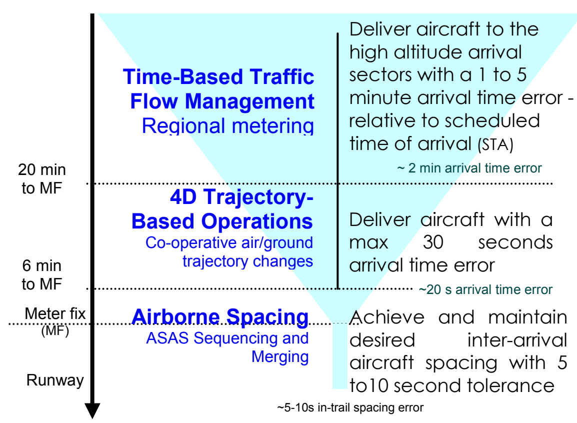

Figure 2: Example time horizons for co-operation between TFM, controllers and flight crews

Integrated Air Ground System Technologies

The CO-ATM concept proposes to move the primary mode of interaction between controllers and flight crews of equipped aircraft from voice to data link. Frequent single task instructions from the controllers to the flight crews are replaced with infrequent trajectory adjustments or spacing clearances. In order to accomplish this trajectory management task effectively controllers and the ground automation need to be informed about the current strategic flight intent and preferences of the aircraft. The integrated air/ground system is explained in detail in [14]. The proposed technologies for the integrated air/ground system are:

- Air traffic service providers equipped with decision support tools for scheduling and trajectory planning.
- Aircraft equipped with flight management system (FMS)
- Addressed data link communication between ground-based decision support tools and FMS to exchange strategic information and routine messages between controllers and pilots
- ADS-B to provide state and short term-intent information to the ground and other aircraft
- ASAS and cockpit displays of traffic information (CDTI) on the flight deck with trajectory planning tools

These technologies enable fully integrated co-operative air/ground operations. It is unrealistic to assume that all aircraft and all air traffic service providers will be equipped according to the standard above. Furthermore, the additional automation cannot be turned on overnight, thus changing the roles and responsibilities of all operators without gradually gaining operational experience. Therefore CO-ATM is designed to phase in new technologies, without directly affecting standard operations. However, it is intended to provide aircraft operators who decide to equip their aircraft early with immediate benefits.

Air Traffic Service Providers

The DAG-TM research has highlighted that one avenue to increasing capacity significantly (2 to 3 times) is to distribute the responsibility for separation of aircraft in a given airspace among multiple operators.

The basic idea of CO-ATM is to split the responsibility for managing air traffic between sector controllers and area flow controllers based on aircraft equipage. Sector controllers control "conventional" aircraft within their sector primarily via voice. Area controllers manage traffic flows of "equipped" aircraft via data link. A major advantage of this approach will be strategic conflict resolution which will reduce the number of conflicts handled by individual sector controllers.

"Equipped" aircraft have as a minimum FMS integrated CNS technologies. CPDLC and trajectory exchange capabilities -uplink and downlink- as well as ADS-B-out will be required for trajectory prediction accuracy. Traffic displays and airborne spacing capabilities will likely be necessary as the number of equipped aircraft increases. These tools will allow the controller to delegate spacing responsibility to the pilot at capacity constrained areas.

New area controller positions are created that overlay multiple sectors. The area positions provide extensive automation support to the controller for conflict detection and resolution with traffic constraints. Routine tasks like handoffs and transfer of communication are conducted by the automation.

Figure 3 depicts a generic example about the re-assignment of air traffic from the current day system to a cooperative system. The sector organization remains basically unchanged as long as the number of conventional aircraft is sufficiently high to warrant today's sector distribution.

While the sector controllers use voice for most clearances and CPDLC for some functions, the area

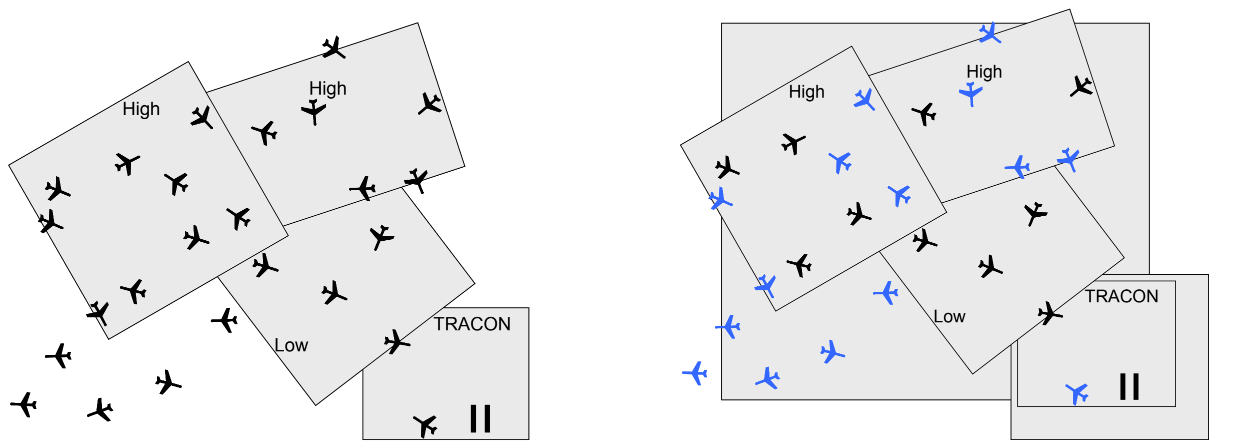

Figure 3.In the current system (left) all aircraft within a given sector are controlled by a single sector controller team. In CO-ATM (right) area controllers manage equipped aircraft and sector controllers control conventional aircraft in the same airspace.

controllers use CPDLC as the primary means of communication. Flight crews of equipped aircraft monitor the area controllers' frequency and are cleared to fly coupled to their FMS along the downlinked trajectory by default. Trajectory changes are coordinated with the area controllers unless autonomous operations have been authorized.

The ground system maintains accurate 4D trajectory predictions for all aircraft based on the best information available. The ground automation monitors these trajectories and the aircraft progress for compliance (security/safety) and conflicts (safety). Identified conflicts are highlighted to the responsible controller. For avoiding and resolving conflicts involving equipped and conventional aircraft, rules have to be defined governing the responsibilities. Near traffic bottlenecks, workload intensive tasks such as the fine-tuning of relative aircraft positioning can be assigned at the discretion of both area and sector controllers

Traffic management and coordination

Increased use of time-based traffic flow management (TFM) is assumed in most far term ATM concepts including CO-ATM. Time-based TFM enables strategic trajectory planning and makes sure that traffic densities remain manageable.

A key requirement for CO-ATM is high flight path predictability. Current day flight path predictions in the ground system are based on filed flight plans with amendments. These descriptions can become obsolete or incorrect in high density situations, in which controllers' have to vector aircraft off their flight plans. The resulting flight path uncertainty has a negative impact on the strategic traffic scheduling process. Additionally, coordination across sector boundaries has to be done explicitly on a case by case basis.

In order to improve the strategic scheduling process and to avoid extensive explicit coordination, precise 4D trajectory descriptions based on FMS routes will replace the flight plan description in the envisioned ground system. Thus, sector and area controllers, traffic managers, and the ground and air side automation share a common understanding of each aircrafts trajectory. These trajectories need to accurately reflect the actual aircrafts' flight path to be meaningful. This can be achieved by utilizing the aircrafts FMS path generation and tracking capabilities. Equipped aircraft exchange trajectories between the FMS and the ground automation via data link. For conventional aircraft flexible FMS compatible procedures are used.

CO-ATM Sector Controller Operations

In the CO-ATM concept sector controllers are responsible for controlling the conventional aircraft within a given sector. Conventional aircraft are handed to sector controllers manually or by automatic handoff functions as today. Track control over equipped aircraft is only transferred to sector controllers manually or if no separate area controller position is used.

Equipped aircraft are displayed with minimum information unless pointed out by other controllers or the automation. This is consistent with today's handling of aircraft controlled by adjacent sector controllers.

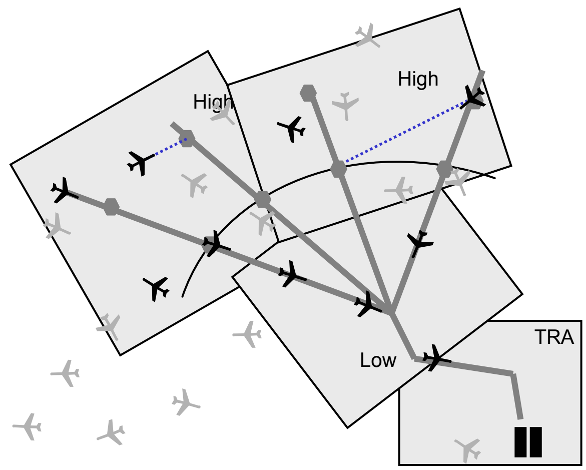

Figure 4: Sector controllers handle conventional aircraft along FMS compatible flight paths.

To increase flight path predictability sector controllers should use FMS compatible procedures whenever possible. Figure 4 indicates an example for an airspace structure that allows controllers to direct aircraft along pre-defined waypoints and routes to a merge point which could reduce vectoring. These modifications can be communicated to the flight crew by voice and entered into the ground system as flight plan amendment. Thus, the ground-based trajectory prediction can be well aligned with the aircrafts intent. DSTs are needed to support sector controllers in conflict probing and implementing appropriate route, speed and altitude amendments.

CO-ATM Area Controller Operations

Traffic flows of equipped aircraft are managed by area controllers with intelligent automation using CPDLC. The area position is a new multi-sector position that is designed to relieve controllers from all routine and tactical tasks. The ground-based automation initiates and accepts transfer of control and communication from and to adjacent sectors unless the controller intervenes. The automation also monitors all aircraft trajectories for TFM compliance and conflicts, and alerts the controller about necessary adjustments.

Trial planning and conflict resolution tools support the controller in determining necessary trajectory adjustments. Flight crews can request preferred trajectories at any time. The downlinked trajectories are checked by the ground system for conflicts and traffic flow compliance to support the controller in determining whether a trajectory change can be approved. When the system achieves some level of equipage where data is available of all aircraft the flight deck system will submit conflict free trajectory change request.

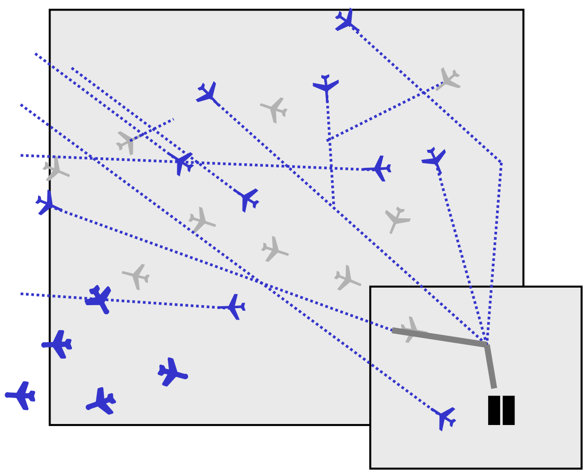

Figure 5: Area controllers handle equipped aircraft with automation support along their most efficient route via data link

Flight crews of equipped aircraft monitor the area controllers' frequency. However during normal operations no radio communication should be required between the flight crew and the controller. Cockpit displays of traffic information are used to maintain flight crew traffic awareness, replacing today's party-line information. Airborne spacing can be assigned by the area controllers for station keeping and sequencing and merging tasks. If so desired area controllers can authorize higher levels of autonomy like limited delegation of authority for separation between aircrafts pairs or full airborne self-separation. Autonomous operations will be monitored by the ground automation for security and safety as well as TFM compliance. The area controller can assist self-separating flight crews in airspace management and conflict resolution, if requested.

If the ground automation, the flight crew, or the area controller detects a conflict or a problem that cannot be resolved with a trajectory change, the area controllers have several options depending on the situation. They can task the flight crew to maintain spacing. They can use voice communication to provide an immediate instruction to the flight crew. They can co-ordinate with the sector controller and hand-off track control and communication to let the sector controller handle the aircraft.

Flight Operations of Conventional Aircraft

Conventional aircraft will notice relatively little impact on their flight operations. FMS-equipped aircraft will be able to make more use of their FMS, thus increasing the flight efficiency. In low density airspace more direct routings and Continuous Descent Approaches (CDA) may be possible. In high density airspace however conventional aircraft will likely get lower priority than equipped aircraft.

Conventional aircraft equipped with airborne spacing capabilities can take advantage of enhanced sequencing and merging operations mostly in terminal areas. CPDLC for Transfer of Communication (TOC) and additional clearances may be used instead of voice communication.

Flight Operations of Equipped Aircraft

Equipped aircraft operations in CO-ATM managed airspace will be very different from today. The high flight path predictability should help schedule equipped aircraft reliably ahead of time and on short notice. Strategic trajectory changes can deliver aircraft on time along the most efficient routes. Low noise continuous descent approaches should be frequently facilitated. Runway spacing will be minimized with ASAS capabilities. Since every equipped aircraft provides a system wide benefit, additional incentives like scheduling and routing priorities could be put in place.

During flight operations, flight crews will experience little voice communication with controllers. Frequency changes will occur less frequently. Flight crews will fly coupled to their FMS at all times, except for short-term conflict avoidance. Flight crews may request preferred trajectories via data link or additional "maneuver room" for example for weather avoidance. Whenever a trajectory change is approved by the area controller/automation, flight crews are automatically cleared to follow this trajectory. A trajectory may include a time constraint that can be managed via climb/cruise/descent speed adjustments from the ground or via airborne required time of arrival functions. Flight crews may also be tasked with additional duties like sequencing and merging.

Airborne self-separation will be authorized by area controllers whenever possible and requested. Reasons for prohibiting aircraft autonomy could be mixed equipage issues in the airspace, the flight crew intends to enter, and airspace or traffic flow requirements. In this case flight crews will continue to co-ordinate trajectory changes with the area controller/ground automation.

Conflict Management

Conflict management is an important issue in an environment with distributed separation responsibilities. The ground automation plays a primary role in conflict detection and resolution especially with regard to the area positions. The conflict detection process is aided by the availability of flight path intent for all aircraft in the ground system. This predictability is largely improved, if equipped aircraft transmit their intent information via data link, and if sector controllers use FMS compatible procedures and make the respective data entries into the ground system. An independent enhanced tactical conflict probe will be required to provide a safety net, like the one proposed for the ground-based Tactical Separation Assured Flight Environment (TSAFE) [4].

In addition to highly reliable automatic conflict probing, specific rules for conflict management and co-ordination will have to be defined. These rules should include: no near-term conflicts between conventional and equipped aircraft may be created by trajectory changes, and that all conflicts will have to be resolved within a certain time frame. Moreover, responsibilities for conflict resolution have to be clearly defined. However, since most area controllers and sector controllers can work in close proximity to each other and share a common air traffic picture, coordination between different positions should be possible building upon today's sector to sector coordination principles.

Transition Approach

The general transition approach proposed in this paper is the conceptual, procedural, and technological integration of ground-based and airborne capabilities – humans and automation - into one integrated air/ground system. This integrated air/ground system can build the foundation for any far-term air traffic system without requiring an upfront explicit definition of all of its final properties. During the transition process pilots and controllers can safely manage new tasks with gradual shifts in roles and responsibilities. The following transitions are fundamental to this approach:

- Transition from flight plan-based sector oriented air traffic control to 4D trajectory-based air traffic management
- Transition the controllers' role from issuing tactical instructions for a single sector by voice to an added role of managing strategic trajectory changes and various levels of aircraft autonomy for multiple sectors by CPDLC.
- Transition the flight crews' role from reacting to tactical controller instructions to actively participating in the trajectory and separation management tasks.

Phasing in Area Positions and CPDLC

One of the intriguing properties of the CO-ATM concept is that it provides for a gradual transition path from today's environment to the target environment with increasing benefits. Sector controller operations and conventional aircraft operations will not experience any drastic changes immediately. The automation assisted, CPDLC integrated area position can be created as a new position. It might be beneficial to design the position as an extension to the current sector controllers' workstations. This reduces training and maintenance requirements and keeps the positions compatible. Controllers can initially monitor multi-sector operations and the automation behavior while separation responsibility stays with the sector controllers. Suggested trajectory adjustments can be coordinated with the sector controllers before data linking them to the aircraft. A number of aircraft have the required equipment or need only minor updates to be able to receive trajectory clearances.

When more trust has been gained, more equipage requirements are met, and the roles and responsibilities have been further defined, the responsibility for separating equipped aircraft can be assigned to the area positions. The number of aircraft controlled by the area position will increase with the number of equipped aircraft. It is expected that the first aircraft to equip will get early benefits, because the controller has more time available in assisting them. Furthermore, open issues can be addressed before the traffic volume increases. In the far-term it is expected that the sector controllers will handle less

Table 1: Possible transition phases from the current system to a CO-ATM system.

Current system	Near-term transition (to 2012)	Medium-term (2012 - 2020)	CO-ATM 2025	Primary Impact
Flight plan-based, sector oriented. Aircraft are frequently vectored off their flight plans, flight information is imprecise, passed from sector to sector,	Predict and distribute 4D trajectories for all aircraft, increase use of pre-defined FMS routes and use ADS-B-out to improve 4D prediction accuracy, increase use of time-based TFM over miles-in-trail	Integrate trajectory downlink and other FMS data to improve trajectory prediction, communicate STA's to aircraft. Enable aircraft to manage to RTA's if equipped	4D trajectory-based. Precise 4D trajectories are shared between flight deck, ATSP, AOC and other potential stakeholders Trajectories from the aircraft are compared to ground-based expectations for compliance,	*security, predictability, flexibility and global inter - operability* *ATM*
Sector controllers issue tactical instructions for aircraft heading, speed and altitude changes in local sectors	Add procedures for sector controller to issue FMS compatible and ASAS spacing clearances inside sector, Add area flow controllers with advanced DSTs to coordinate sequence, schedule and FMS route changes with sector controller and AOC/TMU	Integrate CPDLC with DSTs on area positions, increase authority of area positions to data link trajectory changes and ASAS clearances directly to aircraft. Automate sector / multi-sector /TMU coordination	Area Flow Controllers negotiate strategic trajectory changes with pilots of most aircraft and approve /initiate/terminate increased levels of aircraft autonomy via CPDLC Sector controllers control less equipped aircraft and handle local separation problems if requested.	*Capacity, efficiency, environment* *ATC*
Flight crew reacts to controller instructions, has very little traffic awareness, rarely uses FMS in congested airspace	Add FMS procedures to make more use of FMS in congested airspace, add CDTI to create traffic awareness, add airborne spacing capabilities to delegate limited ATC tasks to flight crew. Receive trajectory uplinks	Integrate CPDLC with FMS and CDTI, enable trajectory requests from the flight deck, increase ASAS capabilities and allow flight crew to manage separation with designated aircraft and/or in designated low density airspace	Flight crew manages coordinated or autonomous operations, uses FMS throughout the flight, is aware of the surrounding traffic, exchanges trajectory modifications with area controllers, chooses traffic and weather optimal routes	*User preferences All weather operations, Safety* *Flight Crew*

aircraft than the area controllers. The number of area flow controllers and sector controllers within a given airspace could be adjusted with the traffic volume.

Increasing Flight Deck Responsibility

Airborne spacing is an initial step to delegate increased responsibility to the flight deck. Airborne spacing can be used as a tool for sector and area controller positions, because it does not require the same high equipage levels. Initial sequencing and merging applications enable controllers and flight crews to gain trust and experience in their new roles without changing responsibilities. Cockpit Displays of Traffic Information will provide increased situation awareness to the flight crews and may be used to make better informed trajectory requests that reflect the flight crew's preference and avoid conflict situations.

Table 1 shows possible transition steps for ATM, ATSP and flight crews from the current system to a CO-ATM system. Obviously the transition will not occur in discrete steps or at the same pace in all areas. Therefore this table represents only one potential approach, indicating two phases: a procedural near-term transition phase and a technological medium-term phase, which will be further investigated in our research on "Trajectory Oriented Operations with Limited Delegation (TOOWiLD)".

Concluding Remarks

New research has provided additional insights into the impact of different concepts on capacity, efficiency, and acceptability. The CO-ATM concept presented in this paper tries to leverage from the lessons learned from previous ATM research. CO-ATM represents a scalable framework for future air traffic operations and a transition path. More research and stakeholder involvement is required to prove the concepts effectiveness and affordability.

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References

[1] Joint Planning and Development Office 2004, Next Generation Air Transportation System Integrated Plan. http://www.jpdo.aero

[2] FAA/Eurocontrol (2001) Action Plan 1 FAA/Eurcontrol Cooperative R&D, Principles of Operation for the Use of Airborne Separation Assurance Systems Version 7.1, 19 June 2001

[3] NASA, 1999, *Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM)*, http://www.asc.nasa.gov/aatt/dagconop.pdf

[4] Erzberger, H., 2004, Transforming the NAS: The Next Generation Air Traffic Control System, 24th International Congress of the Aeronautical Sciences, Yokohama, Japan, August 2005.

[5] Barhydt, R. and Kopardekar, P., submitted, Joint NASA Ames/Langley Experimental Evaluation of Integrated Air/Ground Operations for En Route Maneuvering, The Sixth International ATM R&D Seminar ATM-2005, Baltimore, MD, July 2005.

[6] Lee P, Prevot T, Mercer J, Smith N and Palmer E, submitted, Ground-Side Perspective on Mixed Operations with Self-Separating and Controller-Managed Aircraft The Sixth International ATM R&D Seminar ATM-2005, Baltimore, MD, July 2005.

[7] Callantine T., Lee P., Mercer J, Prevot T and Palmer E., submitted . Air and Ground Simulation of Terminal Area FMS Arrivals with Airborne Spacing and Merging The Sixth International ATM R&D Seminar ATM-2005, Baltimore, MD, July 2005.

[8] Barmore, B., T. Abbott, and K. Krishnamurthy, 2004, Airborne-managed spacing in multiple arrival streams, Proceedings of the 24th International Congress of the Aeronautical Sciences, Yokohama, Japan.

[9] Smith, N., P. Lee, T. Prevôt, J. Mercer, E. Palmer, V. Battiste, and W. Johnson, 2004, A human-in-the-loop evaluation of air-ground trajectory negotiation, AIAA-2004-6260, American Institute of Aeronautics and Astronautics, Reston, VA.

[10]Grimauld I., Hoffmann E., Rognin L. and Zeghal K (2004) “Spacing instructions in approach: Benefits and limits from and air traffic controller perspective”, AIAA 2004-5105, AIAA GNC conference, Providence, RI

[11] Eurocontrol (1999) PHARE ResearchProgramme. http://www.eurocontrol.int/phare

[12] Graham, R., E. Hoffmann, C. Pusch, and K. Zeghal, (2002, 2003) “Absolute versus Relative Navigation: Theoretical Considerations from an ATM Perspective”, ATM2003, FAA/Eurocontrol R&D Seminar, Budapest, Hungary

[13] Prevot, T., Shelden, S., Mercer, J., Kopardekar, P., Palmer, E., and Battiste, V. (2003): “ATM concept integrating trajectory-orientation and airborne separation assistance in the presence of time-based traffic flow management”. Proceedings of the 22nd DASC, AIAA-2003-197. Indianapolis, IN.

[14] Prevot, T., Callantine T, Kopardekar P, Smith N, Palmer E and V Battiste (2004) Trajectory-Oriented Operations with Limited Delegation: An Evolutionary Path to NAS Modernization. AIAA 4th ATIO Forum, AIAA-2004-6449

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