Dynamic Airspace Configuration

Dynamic Airspace Configuration (DAC) is a new operational paradigm that proposes to migrate from the current structured, static airspace to a dynamic airspace capable of adapting to user demand while meeting changing constraints of weather, traffic congestion and complexity, as well as a highly diverse aircraft fleet (Kopardekar et al., 2007).

DAC research consists of three major components: 1) the overall organization of the airspace; 2) dynamically changing airspace to meet the demand; and 3) a generic airspace characterization. The first component relates to a strategic organization of airspace and the creation of new classes of airspace to take advantage of concepts and technologies that are expected to be available by 2025. The second component relates to the dynamic airspace reconfiguration that is needed to accommodate a fluctuating demand. The third component relates to "generic" airspace designs that could promote interchangeability among facilities and controllers by removing structural and functional components of the airspace that would require site-specific training of the airspace.

Problem

The National Airspace System (NAS) is an interconnected system of airports, air traffic facilities, equipment, navigation aids, and airways. Airspace design engineers and air transportation policy makers are continually adjusting system parameters in an attempt to anticipate changes in system demand that result as a consequence of foreseen (e.g. time of day) and unforeseen factors (e.g. weather systems that disrupt the NAS), or because of changes in air traffic management (ATM) policies that govern the operations in the NAS. One key element in guiding the safe and efficient operations of the NAS is airspace management. Airspace management requires predicting the load that is being placed and the capacity possible in the NAS. The current NAS architecture is reaching the limits of its ability to accommodate increases in traffic demand. One key limiting factor is today's sector boundaries which are largely determined by historical use profiles that have evolved slowly over time. Consequently the sector geometry has stayed relatively constant despite the fact that route structures and demand have changed dramatically over the years.

An essential element of the NAS transformation is to use more efficient allocation of airspace as a capacity management technique. The NextGen concept calls for a future system in which daily operations are managed with four-dimensional (4D) aircraft trajectories while the airspace structure and controller resources are continually adjusted to meet user needs. The airspace structural adjustments needed to manage traffic demands and capacity issues are being examined at NASA as part of a set of research activities called Dynamic Airspace Configuration (DAC) under the NGATS ATM-Airspace project.

Prior Research

In 2007 to 2008, we were engaged in two activities in support of the initial stages of DAC research. The first activity involved documenting current state-of-the-art on the airspace design and configuration practices in order to provide a baseline from which the future system can improve upon. The second activity was a human-in-the-loop simulation on the effects of mixed equipage on airspace configuration, as a precursor to designing NextGen airspace configuration is whether the future airspace design should assume segregated or integrated airspace. Each of these activities will be described further in the following sections.

Examination of Current Airspace Structural Components and Configuration Practices

To understand how the air traffic system can transform from current airspace structures and operational practices to what is envisioned in the NextGen operations, current airspace structures and configuration practices were collected from a literature review and a set of discussions with operational experts (Lee et al., 2008). The full report can be found here.

To understand how the air traffic system can transform from current airspace structures and operational practices to what is envisioned in the NextGen operations, we cataloged DAC-relevant airspace components and operations used in the present day, as well as research and near-term operational implementations that are currently being pursued. For example, the current day jet routes are constrained by VOR locations (short for VHF Omni-directional Radio Range), which are part of a radio navigational system first installed in the 1950's. In the near future, VORs are being supplemented by Q-routes which use area navigation (RNAV) capability to generate a greater number of available and potentially less complex routes (Boetig et al., 2004). Q-routes, in turn, may evolve into flow corridors that are being investigated in DAC research (Kopardekar et al., 2007).

Dynamic airspace reconfiguration in current operations has limited options in terms of how sectors and airspace can be reconfigured due to various technological and human factors issues. DAC envisions the future sectors to be substantially more dynamic, changing fluidly with the changes in traffic, weather, and resource demands. Understanding the limitations of the current reconfiguration practices – as well as some near-term solutions outlined in research like Big Airspace and Limited Dynamic Resectorization – will be the necessary initial steps to designing effective airspace reconfiguration support tools and operational concepts in the DAC research focus area.

Effects of Mixed Operations on Airspace Configuration

Future airspace configuration is largely uncharted and one of the interesting areas of research. As the new concepts such as automated separation assurance (e.g. automation detects and resolves conflicts between aircraft that meet minimum equipage requirement) evolve, the airspace must be designed and configured to support them. One of key assumptions that need to be defined before designing new airspace configuration methodologies is to determine whether the future airspace should be segregated or integrated. In the context of airspace with the support of automated separation assurance, segregated (also known as exclusionary) airspace refers to that airspace which only allows aircraft that are supported by either ground-based or air-borne separation management automation. Integrated (also known as non-exclusionary) airspace refers to that airspace which allows both types of aircraft, aircraft that are supported by separation management automation and aircraft that are not supported by such automation. Under the segregated airspace operations where the automation is responsible for conflict detection and resolution; the role of controller is largely confined to monitoring, if deemed useful, under normal operations. Under the integrated airspace operations the automation is responsible for conflict detection of all aircraft and resolution of aircraft that are equipped or capable of being supported by such automation whereas the controller is responsible for conflict resolution of aircraft that are not equipped to support the automated separation.

An experiment was conducted to investigate the effects of Mixed Operations on Airspace Configuration. The goal of the study was to explore the interactions between the equipped and unequipped aircraft in the same airspace as the traffic levels varied for both equipped and unequipped aircraft. The primary equipage requirements for ground-based automated separation management were flight management system and data link while the unequipped aircraft were assumed to be without data link, which prevented the ground-side automation or the controllers to send route changes digitally and hence needed to use voice communications to issue lateral or vertical clearances.

A general hypothesis of the study was that mixed equipage operations would be feasible during moderate traffic levels for both the unequipped aircraft that the controllers needed to control and the total number of aircraft in the sector. It was also hypothesized that there exists a certain critical airspace complexity threshold that once exceeded would make the mixed operations infeasible. In order to explore the effects of traffic densities and the associated airspace complexity, the experiment varied two traffic factors, namely the traffic levels of unequipped and the equipped aircraft.

The controller decision support tools (DSTs) was integrated into a high fidelity emulation of the Display System Replacement (DSR) controller workstation. This DSR emulator was highly configurable to mimic both DSR workstations in the field today and future DSRs with advanced decision support tools. The unequipped aircraft that the controllers managed were shown in full datablock symbology similar to the current day DSR displays while the equipped aircraft were minimized to a target symbol and the current altitude. The targets for the equipped were also dimmed down so that the controllers could effectively ignore them until a conflict arises between an equipped and unequipped aircraft occurred (see Figure 1).

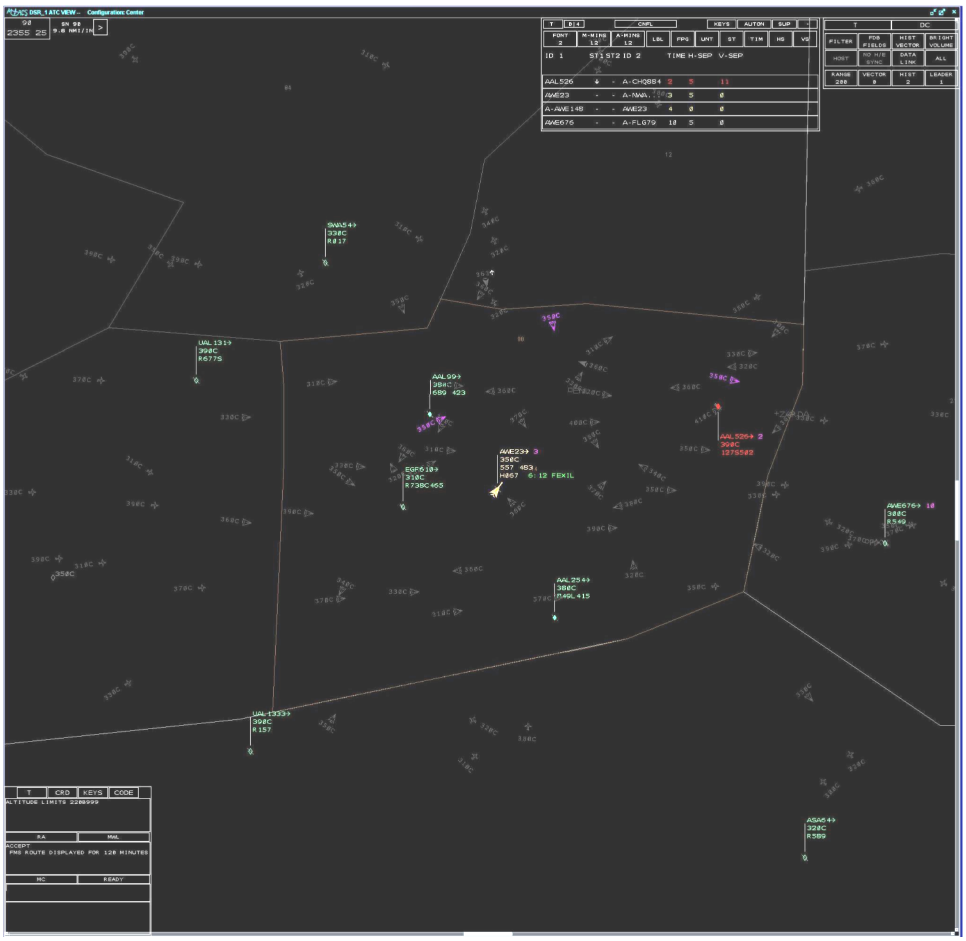
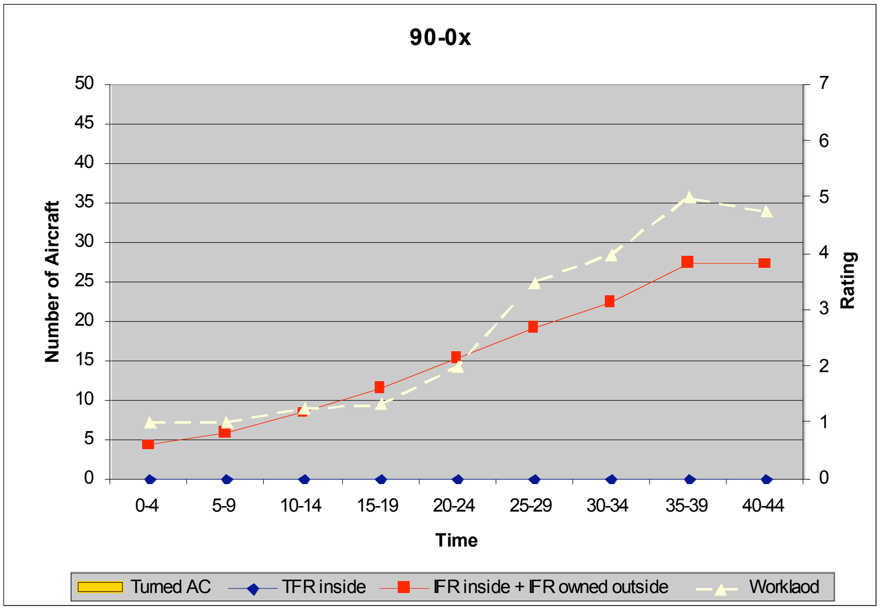
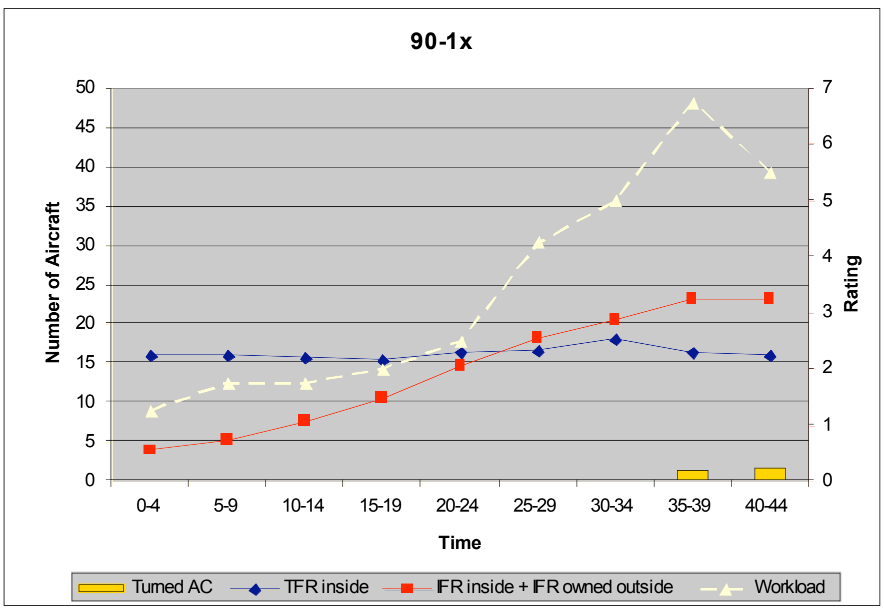


Figure 1: Controller display with equipped (dim limited datablock) and unequipped (colored full datablock) aircraft in mixed separation-assurance airspace

Initial findings indicate that a limited number of unequipped aircraft may be manually controlled in the same airspace as a potentially large number of aircraft that is controlled by the ground automation. Below (Figure 2) is a set of graphs that show the interaction of four of the results gathered for this study (number of aircraft that are turned away due to controller workload saturation, number of automated separation capable (called TFR) aircraft inside sector, number of unequipped aircraft managed by the controller (called IFR), and workload ratings).

The results show that as the number of IFR (i.e. unequipped controller owned aircraft) increased from low to high in each simulation run, workload increased in proportion. The workload also increased moderately with the increase in TFR (i.e. automated separation capable) aircraft from 0 to 45 between simulation runs. The number of aircraft that were turned away due to saturation of controller workload also increased moderately as the number of TFR aircraft increased.





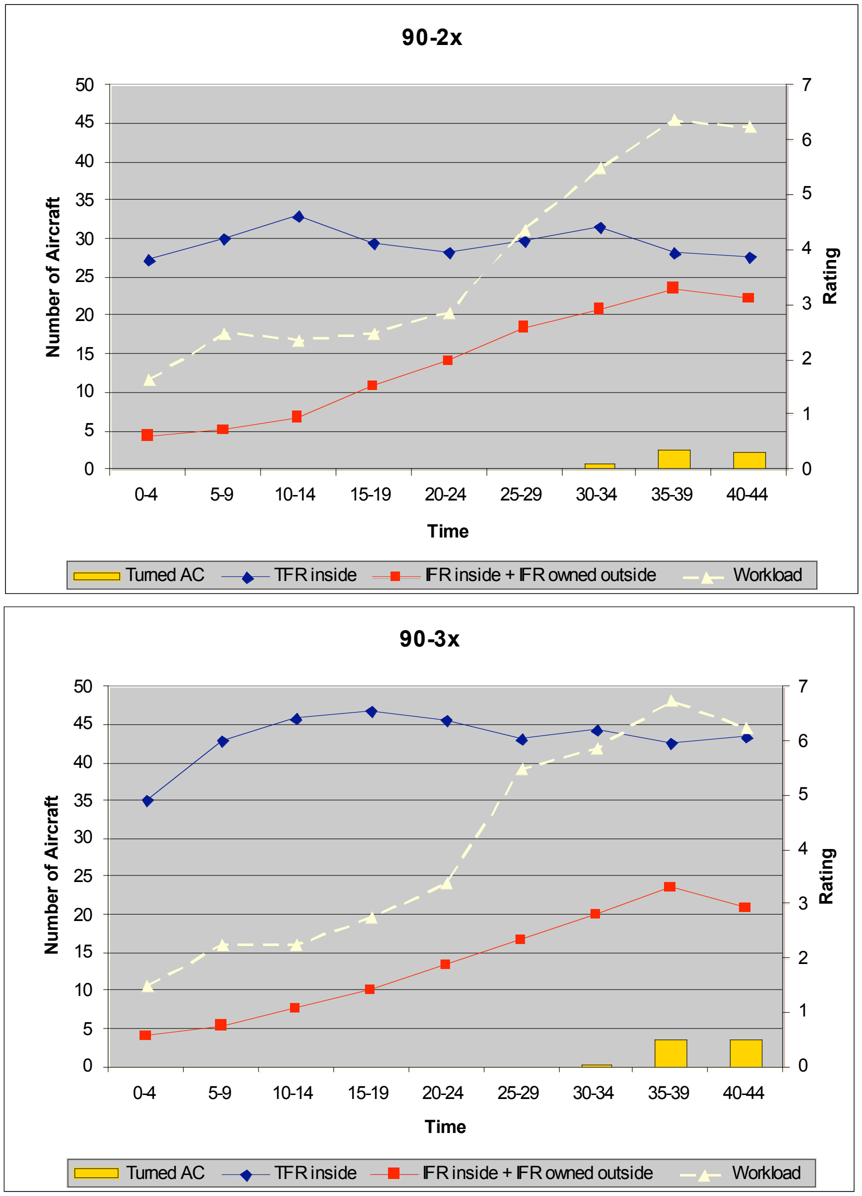


Figure 2: Graphs show interaction of four measurements in sector 90 – number of aircraft that are turned away due to controller workload saturation, number of automated separation capable (TFR) aircraft inside sector, number of unequipped aircraft managed by the controller (IFR), and workload ratings

Based on the quantitative metrics and the feedback from the participants, the actual number of unequipped aircraft that can be handled seem to depend on the number of aircraft that the controllers actively needed to monitor for separation, which in our simulation were the aircraft that were out of lateral conformance (i.e. free track) or climbing/descending aircraft. In addition the workload ratings for the IFR only runs indicate that the availability of conflict detection and resolution tools does not seem to enable a significant capacity increase if the controller has to issue verbal control instructions and maintain awareness of the traffic similar to the way it is done today.

Current Research

A human-in-the-loop simulation study is planned for 2009 to examine the limits of the number and the types of changes in the airspace that the controllers can handle in dynamic airspace reconfiguration in future operations. Some of the interesting variables that may affect the ability of the controllers to adapt to airspace changes include:

- Boundary change methodology – airspace boundaries can change instantaneously from one sector configuration to another, or they can "morph" incrementally
- Rapidity of changes – how often can the boundaries be changed before exceeding controllers' cognitive capability to adapt
- Level of traffic complexity at the boundary change – e.g. number of climbing/descending aircraft, complexity of merge points, etc.
- Number of variables that change at the boundary change – e.g. changes in route structures, radio frequencies, area of responsibility (e.g. change in controlled airspace altogether), etc.
- Amount of coordination and/or training required prior to the airspace change
- Assumptions about decision support tools and separation responsibilities – e.g. automation support for transfer-of-communication, conflict detection, conflict resolution, etc.

Currently, a team of researchers – consisting of algorithm developers who are researching ways to optimally change airspace boundaries, operational experts who understand trigger events that lead to airspace changes in current operations, and human factors researchers – are working together to explore the impact of dynamic airspace changes on the controllers and the feasible limits of the changes that are possible in the future airspace. We are currently working to identify key variables from the above list to test within the planned simulation.

Publications:

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