Preparing for the Future of Collaborative Air Traffic Management

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One of the key areas identified in the NextGen Concept of Operations focuses on Collaborative Air Traffic Management (CATM). Within the NextGen Concept of Operations, this collaboration is expected to continue to occur in a highly distributed environment where operational staff are distributed across many locations and organizations, including flight operations centers, pilots, the Air Traffic Control Systems Command Center, Enroute Centers, TRACONs and Airport ATC Towers (or their future functional equivalents). Significant changes can be expected, however, due to the introduction of new decision support technologies which will enable different approaches to traffic management. These changes in CATM require careful consideration of human factors issues at many different levels, ranging from strategies for distributing roles and responsibilities among different people and technologies, to the design of sensing, communication and decision support technologies and the associated human-computer interfaces, to the training of new procedures and the tools that support them. In this context, this paper focuses on two issues:

- What operational concepts for CATM are likely to be developed over the next 10-15 years?
- What human factors issues need to be considered in the design and implementation of these new operational concepts?

Current projections indicate that, in order to support the needs and desires of the U.S. economy and air travelers over the next 10-20 years, the National Aviation System (NAS) needs to support two to three times current air traffic levels. In order to meet these projected needs, major technological advances have been proposed. These technologies focus on a variety of areas, ranging from the application of new sensors to provide data about aircraft movement on the airport surface, to the installation and use of more advanced Communication, Navigation and Surveillance (CNS) capabilities to support trajectory based operations, to the introduction of advanced decision support tools and automation to support strategic decision making and tactical operations.

One of the key areas that is critical to safely meeting this need for significant enhancements of the NAS concerns Collaborative Air Traffic Management (CATM). The FAA describes this priority area as:

“strategic and tactical interactions with the operators to mitigate situations when the desired use of capacity can not be accommodated. CATM solution set includes the flow programs as well as collaboration on procedures that will establish balance by shifting demand to alternate resources (e.g. routings, altitudes, times).” (FAA, 2007).

It is clear that the success of CATM in the future system will be heavily dependent upon the ability of NAS Service Provider operational staff (traffic managers and controllers in their future roles) and airspace users to collaborate effectively to make use of advanced technologies within new operational paradigms.

Furthermore, this collaboration and coordination must take place in a highly distributed environment where operational staff are spread across many locations around the country, including Flight Operations Centers (FOCs), airline ramp control towers, the Air Traffic Control Systems Command Center (ATCSCC), ARTCCs, TRACONs, and Airport ATC Towers (ATCTs) (or their future functional equivalents), along with the pilots in the aircraft. It is also clear that, in many cases, these individuals will not always be free to interact in real time, requiring different forms of asynchronous communication and coordination. Thus, although these roles will evolve and change over the next 2 decades, it is clear that the NAS will remain a highly distributed, human-centered work system.

CATM is likely to be of central importance in order to enable the airspace users to operate safely and efficiently, both areas of increasing concern as the volume of traffic and fuel prices increase, making it more challenging for airlines, air taxi operators, freight carriers and general aviation operators to maintain viable, cost-effective operations. The operational concepts that have been proposed for CATM for the next 10 years and beyond therefore require careful consideration of human factors issues at many different levels, ranging from:

- Strategies for distributing roles and responsibilities among different people and
technologies (automation)

- The design of procedures that can be effectively carried out
- The selection of sensing, communication and decision support technologies and associated functionalities that should be used
- The design of the human-computer interface
- Training of these procedures and the new tools that support them.

There are also important human factors issues that need to be considered in terms of the integration of human factors considerations into the design process itself.

Because of the significant changes in CATM that are being proposed, including new operational concepts for the functioning of the NAS, very different forms of collaboration and decision making, and technologies that are quite different from those used today, it is critical to that the necessary foundational human factors research be completed in a timely fashion. This basic research must be identified and then completed to ensure effective human-systems integration in the NAS. Thus, the focus of this paper is to identify the human factors engineering issues of greatest concern to the evolution of CATM in the NAS over the next 10-15 years so that necessary research can be conducted to fill existing gaps in these areas.

Methods

In addition to reviewing the relevant literature, structured interviews were conducted with operational staff at the FAA (traffic managers and controllers), with operational staff for flight operators (ATC coordinators, dispatchers and ramp controllers), with aviation human factors experts, with CATM and Traffic Flow Management (TFM) technology developers and with FAA program managers with responsibilities relevant to CATM/TFM. This included:

- Ramp Control - COA at EWR, DAL at JFK, UPS SDF, FedEx at MEM
- Airport ATC Towers - DTW
- ARTCCs – ZOB, ZNY
- FOCs (Flight Operations Centers) – AAL, UAL, SWA, DAL, NWA, NetJets, Jet Blue
- ATCSCC
- NY Port Authority
- FAA William J. Hughes Technical Center (human factors expert)
- MITRE (human factors experts and CATM/TFM technology developers)
- VOLPE (CATM/TFM technology developers)
- MIT Lincoln Labs (CATM/TFM technology developers)
- CDM and NextGen program managers
- Lockheed Martin (technology developers)
- Metron Aviation (technology developers)
- Sensis (technology developers)

Results

Below, we summarize findings regarding likely directions for the future evolution of CATM. We also identify key human factors issues that need to be considered as part of this evolution.

CATM Research and Development Focus Areas

The FAA Service Roadmap for CATM (FAA, 2008) highlighted seven broad categories as the focus for future research and development relevant to CATM:

- Continuous flight day operations (“Performance analysis, where throughput is constrained, is the basis for strategic operations planning. Continuous (real-time) constraints are provided to Air Navigation Service Provider (ANSP) traffic management decision-support tools and National Airspace System (NAS) users. Evaluation of NAS performance is both a real-time activity feedback tool and a post-event analysis process. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations.”)
• Full collaborative decision making (“Timely, effective, and informed decision-making based on shared situational awareness is achieved through advanced communication and information sharing systems. Decision-makers request information when needed, publish information as appropriate, and use subscription services to automatically receive desired information through the net-centric infrastructure service. Decisions are made with an awareness of system-wide implications, including an increased level of decision-making by the flight crew and flight operations centers.”)

• Traffic management initiatives with flight specific trajectories (“Individual flight-specific trajectory changes resulting from Traffic Management Initiatives (TMIs) will be disseminated to the appropriate Air Navigation Service Provider (ANSP) automation for tactical approval and execution. This capability will increase the agility of the NAS to adjust and respond to dynamically changing conditions such as bad weather, congestion, and system outages.”)

• Management of SUAs (“Airspace for special use assignments, schedules, coordination, and status changes are conducted automation-to-automation. Changes to status of airspace for special use are readily available for operators and Air Navigation Service Providers (ANSP). Status changes are transmitted to the flight deck via voice or data communications. Flight trajectory planning is managed dynamically based on real-time use of airspace.”)

• Trajectory flight data management (“Trajectory Flight Data Management will improve the operational efficiency and increase the use of available capacity by providing for improved flight data coordination between facilities. This will enable access to airports by readily facilitating reroutes. Additionally, it will support more flexible use of controller/capacity assets by managing data based on volumes of interest that can be redefined to meet change to airspace/routings. Trajectory Flight Data Management will also provide continuous monitoring of the status of all flights – quickly alerting the system to unexpected termination of a flight and rapid identification of last known position.”)

• Provide full flight plan constraint evaluation with feedback (“Timely and accurate NAS information allows users to plan and fly routings that meet their objectives. Constraint information that impacts proposed flight routes is incorporated into Air Navigation Service Provider (ANSP) automation, and is available to users for their pre-departure flight planning. Examples of constraint information include infrastructure outages, and significant congestion events. special use airspace status, significant meteorological information (SIGMET).”)

• On-demand NAS information (“National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals.”)

More detailed insights are provided by ongoing concept exploration and development projects. Abstractly, some of the major areas that these CATM projects focus on include:

• Strategic planning and coordination to inform tactical decision making, taking into account priorities and constraints of both the NAS Service Provider and the flight operators (e.g., SEVEN, which will allow NAS customers to submit prioritized lists of alternative routing options for their flights; Integrated Collaborative Routing and the use of Flow Constrained Areas, which allow the flight operators to try to resolve the problems associated with a constraint before the NAS Service Provider needs to intervene)

• Integration of information about weather and traffic uncertainty into CATM/TFM decision making (e.g., RAPT, which predicts the likelihood that departure fixes will be open or closed for the next 1-2 hours; weather ensembles to characterize uncertainty in the weather; MITRE’s Probabilistic Air Traffic Management system; Use of NCAR’s NCWF to characterize uncertainty in the weather)

• The use of digital communication to support collaboration among FAA facilities, FOCs and pilots (e.g., TFDM, an integrated system for airport Tower Flight Data Management and communication with flight operators; DFM or the Departure Flow Management tool, a system to support
electronic communication and coordination between airport towers and ARTCCs in order to assign release times for aircraft affected by MIT (Miles-in-Trail restrictions)

- The use of automation to allocate arrival and departure slots to flights to support strategic or tactical metering (GDPs, or Ground Delay Programs to meter arrivals at an airport; AFPs, or Airspace Flow Programs to meter flights through a certain region of airspace; adaptive AFPs, or strategies for tactically adjusting AFPs to respond to the evolution of a weather pattern; DFM; TMA, or Traffic Management Advisor, which tactically meters flights to runways at arrival airports; Control by Required Time of Arrival at a fix)

- Integrated airport surface and terminal area airspace management (e.g., new procedures and decision support tools to help Airport Tower, TRACON, ARTCC and ATCSCC traffic managers better manage departures and arrivals on the airport surface in collaboration with dispatchers, ramp supervisors and pilots; dynamic departure rerouting using Route Segment Coded Departure Routes to reduce delays in dynamically rerouting departures)

- Airspace redesign and trajectory-based operations (e.g., the FAA Big Airspace concept; dynamic airspace reconfiguration; advanced RNAV arrival and departure routes; application of concepts based on performance based services)

- Integrated application of complementary traffic flow management strategies (supported by tools for predicting the integrated impact from applying multiple TFM strategies simultaneously; e.g., integration of TMA with GDPs; integration of RAPT, DFM, TFDM and SEVEN; integrated use of GDPs and AFPs).

Note that the point of identifying these ongoing efforts is twofold. First, the aviation human factors community needs to provide guidance regarding the viability of the associated operational concepts from a human performance perspective. Second, the human factors community needs involvement in the design details. In some cases, existing human factors expertise is sufficient to provide the necessary guidance. However, in other cases, new human factors research is needed.

**Relevant Human Factors Research Issues**

The primary goal of these interviews was to elicit insights regarding the major human factors challenges associated with CATM, and to identify critical tasks where they need to be addressed over the next 10-15 years. A small but illustrative sample of the resultant input is provided below, followed by a more abstract summary of human factors dimensions that the interviews highlighted as critical considerations when defining future operational concepts for CATM, and for designing the supporting procedures and tools.

**Collaboration, Distributed Work and Communication**

“Electronic negotiation of routes is becoming an increasingly important issue. We need a way to ensure that the traffic managers and dispatchers are collaborating with the same picture. Then everyone needs to be able to propose solutions, look at predicted results generated by a model, and collaborate to arrive at a collaborative assessment.”

“With reroutes, different players are best equipped to deal with different parts of the problem. How do we let everyone provide their inputs and then pull all of that into a coordinated whole?”

“Today, the customers have constraints that the service provider doesn’t know. How do we get that information into the mix when considering reroutes?”

“There’s a tendency to push traffic management responsibilities up higher in the system to provide the bigger picture. That doesn’t necessarily make the system more efficient, as knowledge of certain details may be critical to determining the best solution. How do you make sure decision making is pushed to the right level or person, matching the tasks with the people who have the needed expertise, time, motivation and access to data?”

“Some form of chat is very useful because it’s persistent. You can go back and look at what was exchanged if you’re not free at that exact moment.”

**Dealing with Uncertainty**
“We currently present uncertain numbers as if they are deterministic. The users have to fall back on rules of thumb to interpret them. We need tools that really do consider uncertainty and inform the users so they can make decisions.”

“There are different ways to estimate the uncertainty of a weather forecast. Which approach is better? How should the uncertainty be communicated?”

“We can’t burden traffic managers and dispatchers with probability distributions. It works better to tell the user the tradeoffs associated with different options depending on how the situation develops.”

“The hard part is making sure your strategic plan leaves enough options open to handle the uncertainty. In this system, uncertainty changes over time. You need options that you can use when uncertainty is reduced.”

“Helping with risk management is a big issue. What should we display and how should we display it? How do we provide different levels of detail to different people.”

*Information Access and Function Integration*

“You’ve got to be careful with SWIM. We want certain people, such as pilots, to focus their attention on what’s really important for their tasks.”

“SWIM could change the patterns of interaction and information access. That could be good or bad. We need to understand these impacts.”

“Providing appropriate situation awareness is hard. You have different players with different objectives. What do you display to them?”

“We get lots of input when we’re building a new tool, which pushes us to build in options and subtleties that allow flexibility in dealing with specific situations. The end result is often that there are so many options that it’s difficult to do the basic functions that are used 99% of the time.”

“Information overload is a big problem now that only promises to get worse. How do we present the most relevant and most important information? Should we give them more glass or let them access different information and tools on the same glass? What are the best ways to help the user navigate and display the information he needs for different tasks? How do we make sure critical information isn’t overlooked?”

“Right now we have a bunch of stand alone tools for traffic managers and dispatchers. If we want to develop automation suites for these different people, what is needed in terms of functional integration and display integration?”

*Mental Workload and Attention*

“You’ve got to deal with reality. If the workload is too low, you tend to have loss of situation awareness. And if it’s too high, you also lose situation awareness. For example, the dispatchers stop listening to telecons and hot lines when they’re too busy. That information is lost. On the other hand, it may be more work to stop and type in that information so others can see it. What’s the right balance?”

*Training*

“The need for better training is a constant refrain we hear out in the field. This applies in general as well as to new collaborative decision making tools and procedures.”

More abstractly, this full set of interviews emphasized the following issues:

- Considering peak workload demands on performance and staffing requirements
- Developing and sustaining or supporting expertise (feedback, experience and training requirements)
- Integrating tools: Information display and navigation requirements
  - Incorporating intelligent alerts
o Using auditory vs. visual alerts
o Designing to support distributed work
o Tailoring interfaces to specific audiences
o Ensuring appropriate situation awareness

- Dealing with uncertainties
  o Using alternative technologies to collect and process data to develop forecasts
  o Using alternative technologies to help identify and evaluate different strategies dealing with uncertainty (cognitive compatibility)
  o Providing effective information access and display
  o Using distributed work solutions to reduce cognitive complexity
  o Avoiding overconstrained solutions
  o Supporting strategies and tactics that enable effective adaptation

- Incorporating effective safety nets
  o Responding to different contributing causes
    • Brittle technologies
    • Human error
    • Unanticipated scenarios
  o Considering different classes of solutions
    • Technological
    • Human-centered
    • System-level solutions

- Designing effective roles and responsibilities for automation and people
  o Human as monitor
  o Learning and maintaining skills
  o Automation as backup for automation
  o Human adaptation

- Supporting communication
  o Information overload
  o Digital vs. voice

- Integrating of HF in the design process

- Designing organizations, work teams, individual job functions and physical facilities

- Selecting the best form of coordination and collaboration
  o Management by directive
  o Management by permission
  o Management by exception
  o Real-time interactive collaboration
  o Asynchronous coordination through constraint propagation.

Finally, while such a list of important human factors considerations serves to direct attention to important issues, it does not give justice to one of the major overriding human factors concerns:

How do the design decisions based on consideration of these individual issues interact to influence performance in the actual work environment?

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References

FAA, (2007). Improve collaborative air traffic management