iFly:
Human Factors in Autonomous Aircraft Operations (Airborne Self-Separation Environment)

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Introduction

The current air traffic management (ATM) system quite naturally has its intellectual roots in World War II. As air transport grew in the 1950s the people with the most experience in managing large numbers of aircraft in confined spaces were commanders in the various air forces from that war. Thus, they were the people selected to organize and manage the growing of the civilian air transportation systems, and the resulting system that we still use today is essentially a military command and control system primarily dependant on technologies developed during WWII: radar and radio navigation aids.

For more than 20 years, it has been recognized that the increases in volume and distribution of air traffic requires dramatic changes to the task of managing air traffic just if we are to maintain the current level of safety. Over that same period, the Western world has seen loss of many of the classic airlines, e.g., PanAm and TWA, in part due to the inefficiencies of the current system. For example, a 1988 study showed that the economic impact of the inefficiencies of the air traffic control (ATC) system was a loss of more than $8 billion U.S. dollars in excess fuel and time losses in the U.S. alone. Given just the increases in fuel costs over that period, it is reasonable to imagine today that number has more than doubled.

The search for more effective ways to safely move more air traffic efficiently has a long history. For example, in 1991 NATO and FAA sponsored Advanced Research Institute of European and U.S. scholars to look at automation and systems issues in air traffic control [1]. This effort was perhaps one of the earliest attempts to step out the box and use a true interdisciplinary approach that purposefully looked for scholars outside of the traditional set of air traffic practitioners to contribute to the discussion. This attempt led to a book full of discussions and new ideas regarding air traffic management (ATM). Wise [2] discusses, for example, pros and cons of formation takeoffs to reduce departure queues or even formation landing for airlines, which is not only safe but also highly efficient, or to assign all separation duties to the pilot. He also calls the assumptions of the existing ATM system - “controlled airspace is safer and more efficient” - into question [3].

In recent years, the European Union (EU) has sponsored a series of research programs that attempted to evaluate a set of different approaches to improving the safety and efficiency of its air traffic system. The European Commission 6th Framework Program’s (EC FP6) call for innovative air traffic management research in the area of ”aeronautics and space”, led to the development of the iFly[1] project definition in accordance with the future ATM system envisioned by the EU and the North American government agencies for the 2020+ time frame. Most recently, the EU has funded the Single European Sky ATM Research (SESAR) program to organize that effort in a way to develop a modern air traffic management system.

[1] This research has been performed with support from the European Commision's project iFly FP6-TREN-037180

As one would expect, the range of approaches proposed have been as numerous and varied as the teams that have proposed them.

The iFly program is aligned with the European SESAR [4] and US NextGen [5] concept of operations, which define the ground and airborne technologies needed to ensure an effective future air traffic management system. iFLY ushers in a new ATM paradigm for all types of aircraft that could benefit from a more efficient air transport system. iFly focuses on a solution based on a highly automated and distributed ATM design for en route traffic, which will take advantage of autonomous aircraft operation capabilities (free routes).

Besides abolishment of the traditional fixed route structure, iFly also signifies a transfer of responsibility for separation of aircraft during the en route phase of flight from a ground-based ATM back to the flight crew. In other words: from centralized management to a decentralized approach.

Future Airspace

Perhaps the most significant change in an ATM system like the one envisaged in iFly is the dramatic restructuring of the airspace. Currently, the iFly concept of operation (ConOps) has defined three basic types of airspace (Fig. 1):

- Managed airspace (MA) is limited to the high-density areas like traffic management areas (TMA) and some other dynamically designed zones (i.e., restricted use airspace or military airspace). In MAs, all aircraft are subject to traditional ATC clearances. Operations assignment and the associated separation responsibility will be managed by ground-based ATM.
- Unmanaged airspace (UA) is all airspace where no traditional air traffic control services are provided. In UA, the responsibility for separation is the complete responsibility of the airspace user.
- Performance based airspace (PBA) includes all remaining airspace. In PBA, the aircrews will necessarily be operating in a self-separation capable aircraft and will be responsible for separation, using autonomous flight rules (AFR) [6]. The en route phase of commercial flights, from exiting the departure TMA to the entry of the arrival TMA, will entirely take place inside the PBA.

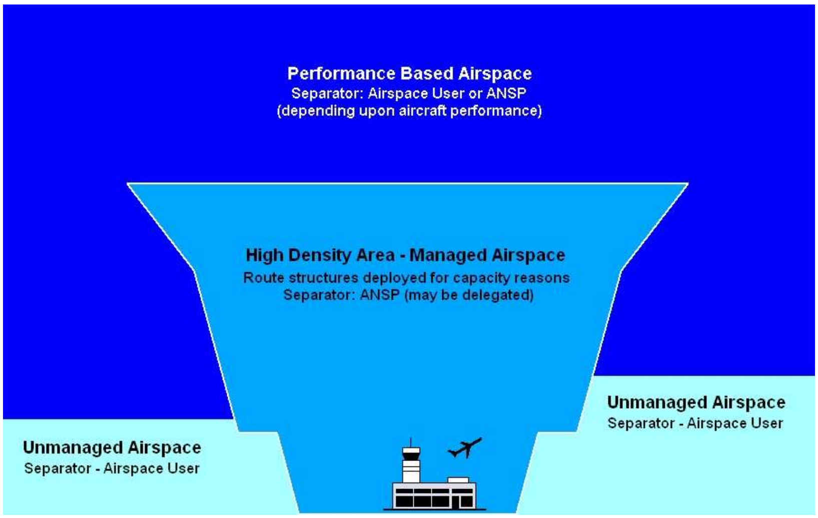

Figure 1: iFLY Airspace Types

The change of the current ATM system, together with the implementation of the performance based airspace, will allow for greater freedom for each aircraft to compute optimal, userpreferred business trajectories and to determine separation maneuvers in an autonomous way.

Actors, Tasks and Responsibilities

In the previous several decades, the ATM actors in controlled airspace, in addition to the aircrews, have been the Air Traffic Controllers [ATCOs], who have been tasked to provide safe, orderly and efficient movement of the whole traffic system. This success of the ATCOs in keeping aircraft more than five miles apart has resulted in many flight crew members minimizing the importance of maintaining their traffic awareness.[2] Of course, many pilots have maintained the ability to create a rough picture of what is going on in their vicinity (e.g., traffic and weather situation) by looking out of the window (when conditions permit) and listening to radio communication. But under the current system, they are committed to follow ATCOs' instructions and to react to Traffic Alert and Collision Avoidance System (TCAS) warnings.

With the introduction of the proposed iFLY system and the associated shift of responsibility back to the flight crew, in performance based airspace pilots will once again need to obtain, maintain and occasionally regain a high level of situational awareness to accomplish their restored task of self-separation.

To get a better understanding of the impact of upcoming changes on the tasks and responsibilities of the aircrew, a comprehensive goal-directed task analysis was performed to assess the actual responsibilities and tasks of commercial and corporate aviation pilots during the en route phase of flight. Semi-direct interviews with four experienced pilots were conducted. Associated with the four high- level tasks in aviation, namely aviate, situate, navigate and communicate, the following 13 high- level tasks have been identified [7;8]:

Aviate	Aircraft systems monitoring
	Fuel management
	Passenger safety and comfort management
	Technical failure/emergency management
	Logbook and flight documents management
Situate	Radio watch-over
	Weather and terrain monitoring
Navigate	Airborne separation management (respecting the assigned separation distance)
	Monitoring aircraft profile and speed
	Conflict management (aircrew is responsible to manage short-term conflicts; TCAS management)
	Trajectory determination and flight plan changes management
Communicate	Operational and commercial communication with the airline base
	Communication with ATC

[2] *When a person spends hours and hours over many years rarely, if ever, seeing another aircraft, it quite naturally results in the extinguishing of the search behavior.*

An analysis of the critical high- level tasks during a typical iFLY mission from pushback to parking has resulted in the identification of six sub-phases and a list of anticipated corresponding responsibilities/tasks and actors. While iFly only addresses on the en route phase, the sub-phases are included for completeness.

1. **Pre-flight**: Flight operations centers (FOC), as well as airspace users operating without FOCs, have been identified as pre-flight actors. These actors are responsible to develop their shared business trajectory (SBT)[3]. This SBT will contain all pre-planned flight trajectory, from take-off to landing, is ideally integrated with the taxiing and handling processes in a gate-to-gate ATM concept and available to all airspace users and Air Navigation Service Provider (ANSP). The main change in this phase refers to the freedom to select the most optimal flight route to the final destination according to the business policy of the company (time, costs, fuel consumptions, passenger comfort, etc.). In contrast, the airline has to ensure the proper equipment of the aircraft and the appropriate training of the flight crew to ensure a safe operation in the PBA.

2. **Start-up and Taxi**: Pre-flight procedures will basically remain unchanged. System checks may change based upon new functionalities or (when relevant) completely new display formats. Within the scope of iFly, taxiing will be performed according to existing rules and procedures.

3. **Departure:** At the moment, no changes are envisaged regarding the current departure and initial climb until the aircraft reaches the border of the TMA. New procedures will be developed to ensure the safe hand-over of the separation responsibility from the ATCO to the aircrew. When leaving the TMA, the ATCO will be required to ensure that the iFLY aircraft is conflict-free when entering the PBA.

4. **En Route**: Upon entering TMA, the flight crew assumes complete responsibility for the safe, efficient, on-time operation of the flight. Furthermore, the flight crew becomes solely responsible for their separation from all other aircraft and other hazards (e.g., terrain and weather) and for adhering to all relevant flow management constraints.

   As such, the aircrew also assumes responsibility for the accurate accomplishment of the following sub-functions/tasks:

   - ✈ Trajectory management
     - × Tactical de-confliction
     - × Avoidance of weather hazard areas (WHA)
     - × Avoidance of restricted airspace areas (RAA)
   - ✈ Maintenance of the aircraft reference business trajectory (RBT) update management
   - ✈ Compliance with all strategic flow management requirements (Required Time of Arrival, RTA)
   - ✈ Monitoring of other aircraft RBT update alerts and data communications

   The number of additional tasks and their workload might seem quite high, but it is counterbalanced by the loss of a number of communication tasks and by the fact that en route is generally the lowest workload phase of the flight.

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[3] *As defined in SESAR definition phase, deliverable 3, The ATM Target Concept, DLM-0612-001-02-00a, September 2007.*

5. **Arrival**: The aircrew will have to ensure their arrival at the TMA in compliance with their controlled time of arrival (CTA) or required time of arrival (RTA) at the predefined TMA entry point. They have to meet all the air traffic requirements of the arrival TMA. Once the aircraft has entered the TMA, there are currently no significant changes envisaged with current arrival procedures.
6. **Landing/Taxi to Parking**: No significant changes are expected in this phase.

Flight Crew Needs and Human Factors (HF) Issues

Operating an aircraft in the PBA will be more challenging for the flight crews who have only operated in controlled airspace, but in reality only slightly more challenging that normal en route VFR (Visual Flight Rules) workload levels. But the flight crew will have to cope with more tasks, a return of basic separation responsibilities, possibly higher workload under certain conditions (e.g., severe weather) and they will have complete responsibility for all types of situational awareness (e.g., traffic and mode awareness).

To assess the essential information needs of the flight crew to accomplish the airborne self-separation mission and to determine the appropriate level of automation, it will be necessary to study the following sub-tasks [6;10]:

- Traffic monitoring
- Conflict detection
- Conflict resolution
- Conflict prevention
- Replanning
- Inter-traffic/traffic-FOC communication

At this point, it becomes clear that today’s traditional airline operations probably do not provide the information to analyze the iFLY tasks. It is, however, hypothesized that the flight crew will need to be provided with high quality ergonomically designed traffic and navigation information and in certain circumstances may need to be assisted by some level of automation and perhaps some decision support tools.

Currently flight crews use the traffic collision avoidance system (TCAS) display as a backup to ATC and to help them achieve a minimal level of traffic situational awareness. But in an iFLY or SESAR-like operational environment, TCAS information will not be sufficient. A cockpit display of traffic information-like (CDTI) system will probably be a better tool to help the aircrew to develop and maintain a high level of traffic situational awareness by providing basic data about position, speed and sometimes future state information about aircraft in the vicinity.

The most important need will probably be to assist the crew in the prevention, detection and resolution of a significant conflict. In this domain, it is assumed that the aircrew will be in a managing position. The detection of imminent collisions will be automated and will be executed in the background. The crew will be alerted in case of imminent conflicts along with several solution strategies, which are assumed to be sorted and filtered for the crew by using different criteria (e.g., fuel/time optimization, weather and wind criteria, passenger comfort, etc.) to opt for the most optimal solution in the given situation. The aircrew will have the possibility to alter different parameters of the maneuver (e.g., aircraft speed, waypoints, altitude) according to their needs and own assessment of the situation.

Road Ahead

It is reasonable to estimate that some new types of automation will be needed on iFLY flight decks in order to enable the flight crew to manage their PBA tasks and responsibilities. In particular, the automated processes (e.g., conflict detection, conflict resolution, tools for calculating optimal trajectories, etc.) will need to keep the flight crew in the loop. This will enable them to be aware of actions planned and to understand and develop trust in the given solutions. If the flight crew can stay in the loop, they will be more able to make appropriate decisions and act properly in case of a system failure. For these tools to be effective, the designer will need a clear understanding of not only the data needed but also the most effective way of presenting it to the flight crew.

Perhaps the most basic issue is that these tools and decision aids will need to be developed to support the aviate, situate, navigate and communicate tasks. Very high quality HMI's (Human Machine Interface) and support tools will need to be designed and tested to depict the necessary information in an intuitively obvious way that supports the aircrew in making a quick and easy decision relevant to the implementation of required maneuvers(s). The focus needs to be on what the joint cognitive airborne system (human-machine) is expected to do under the iFly A3 (Autonomous Aircraft Advanced) concept instead of thinking about what man or machine is doing separately from each other. Rather than avoid allocating roles (functions) between man and machine, think in terms of function congruence [11].

In the end, the quality, efficiency and safety of the iFLY (or similar) system will boil down to the quality of the preparation done before the design starts. It is hoped that in the next year, the iFLY team will be able to contribute to a firm human factors foundation upon which to build SESAR.

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