Situation Awareness, Automation & Free Flight

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Keywords: Automation, Situation Awareness, Workload, Free Flight, ATC

ABSTRACT

Free flight represents a major change in the way that aircraft may be handled in the U.S. National Airspace System. It has the potential of significantly increasing airspace utilization and thus improving aircraft throughput. The degree to which these objectives can be met, however, without compromising aircraft safety, depends on establishing appropriate changes in the air traffic control system. These changes may include significant incorporation of new air traffic management and cockpit technologies. Studies that examine the affect of automation on situation awareness will be reviewed. These studies indicate that while certain forms of automation may be advantageous, other types of automation may induce losses in situation awareness that can lead out out−of−the−loop performance errors. A recent study was also conducted that examined changes in the locus of control between ATC and the cockpit using existing technology. This study provides an objective evaluation of the effects of free flight on controllers' ability to maintain an accurate and complete picture of the traffic situation in order to provide needed monitoring and separation functions. The study revealed that aspects of free flight can significantly hinder the situation awareness and performance of controllers. The results of this study provide information for better defining how free flight should be implemented and for determining needed design and procedural modifications to support the concept.

INTRODUCTION

With the advent of new technologies such as GPS and TCAS, the concept of free flight may be introduced as a major change in the way that air traffic is managed in United States air space. RTCA[1]. provides one idea of how free flight might be implemented. Under free flight, aircraft would no longer be restricted to flying the air corridors which comprise only approximately 5% of available airspace. Aircraft pilots would have more control over setting their routes and over making dynamic changes in the flight path, altitude and speed of their aircraft while under IFR conditions. The ability to fly to destinations directly, instead of along fixed routes, may create significant advantages in terms of both time and fuel savings for the operators of aircraft and particularly for major airlines. It also allows pilots to have more control in avoiding weather and dealing with other factors which crop up during a flight.

The exact way in which free flight will be implemented has not yet been determined. Opinions on the changes in procedures, displays and automation needed to support free flight vary as do concepts regarding the new roles of the pilot and the controller under free flight. Any decision on whether and how to implement free flight conditions needs to be driven by information on the degree to which a given concept can be accomplished without compromising aircraft safety.

A central factor in ensuring this objective will be the degree to which controllers and pilots have sufficient situation awareness (SA) to maintain safe separation in flight. Situation awareness has long been recognized as crucial for pilot performance. In addition, SA is critical for controllers who must maintain up−to−date assessments of the rapidly changing location of each aircraft (in three−dimensional space) and their projected future locations relative to each other, along with other pertinent aircraft parameters (destination, fuel, communications, etc...)[2,3]. Controllers have historically called this *the picture* — their mental model of the situation upon which all of their decisions hinge. This picture will continue to be important in any future system in which they are called upon to insure air traffic separation, or to monitor the separation achieved by other agents — human or automated.

DESIGNING FOR AUTOMATION

Many of the technological changes that are being proposed to enable free flight involve the use of automation. Human operators acting as monitors of automated systems have, however, exhibited problems in detecting system errors and performing tasks manually in the event of automation failures[4−6]. This issue needs to be explored carefully, in order to insure that air traffic system safety is not inadvertently compromised. In examining problems with automated systems, it becomes apparent that current automation approaches may be at fault in that they can compromise SA and lead to out−of−the loop performance decrements

With many automated systems, forming the higher levels of SA (comprehension of the situation and projection of future actions) can pose a significant difficulty. Evidence of lower Level 2 SA (comprehension) under automated conditions has been found [7,8]. This problem has been directly linked to several major factors [8]. (1) Vigilance decrements associated with monitoring, complacency due to over−reliance on automation, or a lack of trust in automation can all significantly reduce SA as people may neglect monitoring tasks, attempt to monitor but do so poorly, or be aware of indicated problems, but neglect them due to high false alarm rates. (2) Passive processing of information under automation (as opposed to active manual processing) can make the dynamic update and integration of system information more difficult. (3) Changes in form or a complete loss of feedback frequently occur either intentionally or inadvertently with many automated systems. Furthermore, evidence suggests that in many ways current automation approaches fail to achieve desired reductions in operator workload as monitoring is a demanding task and the automation itself introduces new kinds of workload [6,9,10].

An alternate design approach is being explored that focuses on utilizing intermediate levels of automation (LOA) that integrate the human and the automated system in substantially different ways[11]. Automation has typically decreased operator SA through implementation strategies that remove the operator from involvement in system operation. An alternate approach to automation focuses on enhancing SA by keeping the operator involved in the task. This can be accomplished by determining a level of automation (LOA) that minimizes negative impacts on SA. At intermediate levels of automation the human may be far more involved in the operation of the system and able to deal more effectively with the automated system when needed. Thus, LOA represents a strategy for improving the functioning of the overall human−machine system by integrating the human and automated system in a way that allows the human to function effectively as part of the system (human−centered automation).

Level of Automation Taxonomy

To explore the benefit and costs of various levels of automation on overall human−machine performance, a ten level taxonomy of level of automation was developed that considers functions that need to be performed across a wide range of systems[11]. Four generic functions intrinsic to many domains, including air traffic control and flight were identified: (1) monitoring/ scanning displays to perceive system status, (2) generating/formulating options or strategies for achieving goals, (3) selecting/deciding on a particular option or strategy, and (4) implementing/carrying out the chosen option. Ten levels of automaton were formed on the basis of allocating each role to the human, computer or shared between the human and computer. They include (1) Manual control, (2) Action support, (3) Batch processing, (4) Shared control, (5) Decision support, (6) Blended decision making, (7) Rigid system, (8) Automated decision making, (9) Supervisory control , and (10) Full automation, as shown in the taxonomy depicted in Table 1.

Empirical Analysis

To explore the effect of the LOA taxonomy on situation awareness, workload and performance, it was implemented within a simulation of a dynamic control task[11].

Table 1 Level of Automation Taxonomy[11]

ROLES				
LEVEL OF CONTROL	MONITORING	GENERATING	SELECTING	IMPLEMENTING
(1) Manual Control	Human	Human	Human	Human
(2) Action Support	Human/Computer	Human	Human	Human/Computer
(3) Batch Processing	Human/Computer	Human	Human	Computer
(4) Shared Control	Human/Computer	Human/Computer	Human	Human/Computer
(5) Decision Support	Human/Computer	Human/Computer	Human	Computer
(6) Blended Decision Making	Human/Computer	Human/Computer	Human/Computer	Computer
(7) Rigid System	Human/Computer	Computer	Human	Computer
(8) Automated Decision Making	Human/Computer	Human/Computer	Computer	Computer
(9) Supervisory Control	Human/Computer	Computer	Computer	Computer
(10) Full Automation	Computer	Computer	Computer	Computer

Results indicated that LOA significantly impacted both task performance and the out−of−the−loop performance problem. Specifically it was found that system performance was enhanced by automation that provided aiding in the implementation aspect of a task, but was hindered at LOAs involving joint human−automation option generation (such as encountered with expert systems). Computer aiding in the action selection (decision making) aspect of a task did not significantly impact performance when compared to purely human decision making. While performance at the high end of the LOA taxonomy was better than purely manual performance, it was never as good as when the automation only assisted in the manual implementation aspects of the task, without becoming involved in the higher level cognitive aspects.

The operators' ability to recover from and perform during automation failures significantly improved with LOAs that required some human interaction in

task implementation. Following an automation failure, time−to−recover task control and manual performance was worse with LOAs that allowed advance queuing of targets (Batch Processing and Automated Decision Making). Thus automation strategies that allow operators to focus significantly in advance of current operations may contribute to out−of−the−loop performance decrements. Situation awareness and workload were also found to be affected by LOA. Reductions in workload and corresponding improvements in operator situation awareness were observed with higher LOA that incorporated joint human−computer or computer selection of options to implement.

Even when full automation of a task may be technically possible, it may not be desirable if the performance of the overall system is to be optimized. Intermediate levels of automation may be preferable for certain types of tasks and certain functions, in order to keep human operators’ situation awareness at a higher level and allow them to perform critical functions. In relation to automation changes proposed with free flight, these results indicate that in order to keep controllers' SA at a high enough level to intervene effectively, automation may need to be designed at a lower LOA allowing the controller to be involved in critical decision functions.

CHANGES IN LOCUS OF CONTROL

Another aspect of free flight involves a shift in locus of control regarding dynamic flight path decisions from the ground to the flight deck. Significant challenges exist in providing aircraft with sufficient information to be able to make dynamic decisions that do not place their aircraft into an unsafe proximity with other aircraft. In addition, the role of the controller under free flight may be changed significantly. As the ability to control the actions and paths of aircraft is removed from the controller’s purview, his/her role changes to that of monitor, taking action only when separation problems are detected. The ability of the controller to perform in this role under these conditions needs to be seriously evaluated, however, as the controller’s SA may be significantly degraded under free flight due to changes in the dynamics and predictability of aircraft in the airspace.

The concept of free flight represents a significant change in the dynamics and behavior of the aircraft operating in a controller’s sector. With free flight, it is likely that the ability of the controller to determine why an aircraft is behaving in a particular way will be greatly reduced (e.g. does a deviation of an aircraft from its current path represent an intentional action or a problem the pilot is not aware of? Is the pilot aware of potential conflicts or altitude problems?) Not only will controllers need to be able to detect changes in aircraft flight path, speed and altitude; the controller will also need to assess its impact on separation with other aircraft, special airspace or given standards (such as airport approach volume limits or minimum altitude restrictions). Being able to do so depends on understanding aircraft intent and having an idea of what the pilot does and does not know about. Acquiring this kind of information under free flight conditions may dramatically increase the communications requirements and significantly alter the behavior of the controller. Communications may occur more for the purpose of acquiring information from the pilot or providing information to the pilot instead of to provide control actions, and may be much more frequent and time consuming. An increase in controller workload may result from this change, as opposed to the decrease in workload that is generally assumed to occur with a reduction in control required under free flight. With significant new demands present in order for the controller to be able to interpret aircraft actions and understand their significance for aircraft safety, there is a real possibility that SA may be degraded if the controller cannot keep up with these requirements.

In addition, the predictability of aircraft movement will significantly decrease under free flight. In today's system, controllers gain a significant amount of information about how the aircraft is going to behave from knowledge of their assigned flight path and destination. There are a limited number of ways that aircraft will proceed through a given airspace in accordance with a given flight path and the aircraft's intended activity in that sector (e.g. approach, departure or en route). Deviations from these norms can usually be quickly detected by the controller. With free flight, aircraft may come from almost any direction into a sector, change paths many times without controller action or approval and depart the sector in almost any direction. With this loss of aircraft predictability, the ability of the controller to project ahead to determine potential separation problems may be greatly reduced. The ability to project the future actions of aircraft (the highest level of situation awareness) is critical to the controller's ability to make timely control actions. Thus, a significant concern exists as to controllers' ability to understand the significance of aircraft actions and adequately predict impending problems in order to be able to manage traffic effectively in their new role. A study was therefore conducted to examine the effect of the free flight concept on a controller's ability to create and maintain an accurate picture of the air traffic situation and its impact on controller workload, control strategies and performance[12].

Some critical aspects of free flight were examined: the use of direct routes, the ability of pilots to deviate from flight plans of their own accord, and the requirement to inform controllers of pilot intentions in making such deviations. Four conditions, representing increasing higher levels of free flight were presented. (1) Baseline − in which current ATC practices were used, (2) Direct Routes − in which all flight plans were filed with direct routes (with the slight modification of avoiding restricted airspace areas), (3) Direct Routes & Deviations with Intent − which was the same as the Direct Route condition, however pilots were also able to deviate at will from their filed flight plan after notifying ATC that they were doing so. The controller's role was to only reject or modify such deviations if necessary (on an exception basis), and (4) Direct Routes & Deviations − which was the same as the above condition, however pilots were not required to inform ATC of their intentions, but could simply deviate at will. The controller's role was again to intervene only if necessary to insure safety of flight. All other aspects of the ATC system, including procedures and technologies were held as consistent as possible between these conditions. Ten active controllers served as participants in the study, each conducting two simulated air traffic scenarios under each condition.

Controller performance was rated by subject matter experts (supervisor level controllers from the facility) as significantly lower in the Deviations with Intent and Deviations without Intent free flight conditions, as compared to the Baseline condition.. A total of 7 operational errors occurred in the highest level of free flight (Deviations without intent), as compared to only 6 in the other three conditions combined. Due to the small number of operational errors, which is typical in ATC simulations, no statistical conclusions could be drawn, however this number is quite large and worthy of concern. Controllers were poorer at marking flight strips and prioritizing tasks in the Deviations without Intent conditions, and were also rated as providing significantly less information in the Deviations with Intent and Deviations without Intent conditions, as compared to the baseline condition.

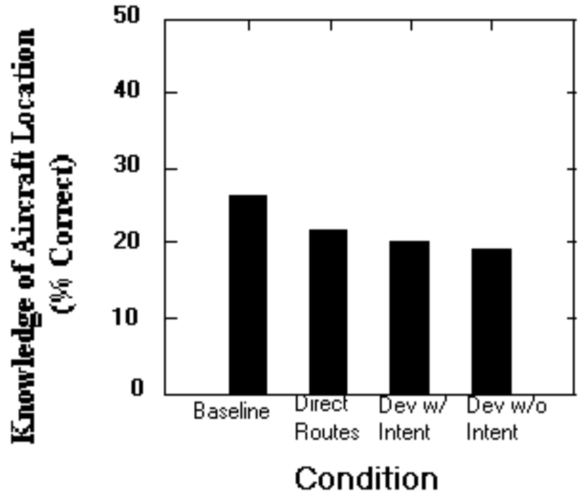

Figure 1 Impact of free flight on controller SA

SA was evaluated via the Situation Awareness Global Assessment Technique (SAGAT)[13,14] ANOVAs conducted on the SAGAT data revealed significant losses in SA on some variables at higher levels of free flight: Knowledge of aircraft location, awareness of aircraft with uncompleted clearances, awareness of correct receipt of aircraft clearances, awareness of conformance to clearances, awareness of impact of weather on aircraft, and awareness of next sector for aircraft. An example of this is shown in Figure 1. Controllers were aware of fewer aircraft, and for those aircraft displayed lower situation awareness at the higher levels of SA (comprehension and projection). This is similar to the results found under passive monitoring of automation. Workload was also impacted by free flight. NASA−TLX scores showed that workload was rated higher by controllers at higher levels of free flight (Figure 2).

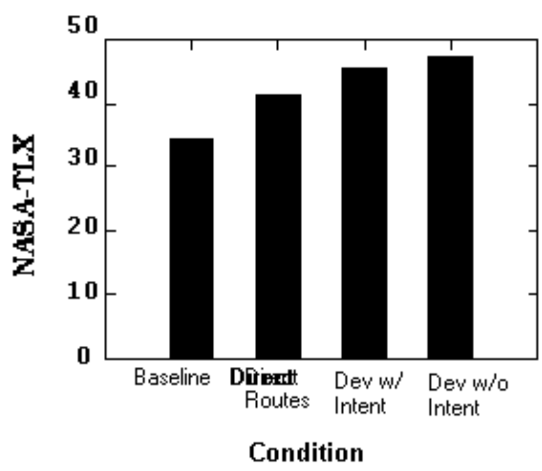

Figure 2 Impact of free flight on controller workload

This study was an initial exploratory investigation of free flight that focused only on controllers. It did not investigate SA of pilots who would be operating under free flight, and did not investigate potential for separation problems which would also be a function of the technologies and displays which might be provided to both pilots and controllers in the future. Each of these issues needs to be examined independently to assess their worth (or problems) in assisting in free flight.

It does however indicate that if controllers are expected to act as passive monitors of free flight air traffic, their awareness of the state of air traffic may be reduced, their workload may increase, and their ability to intervene in a timely manner may be limited. Future implementations of free flight need to consider alternate allocations of responsibility between the controller and pilots. In addition the use of technologies & displays for dealing with these concerns needs to be more explored. It is possible that compensating mechanisms may be found to provide the levels of situation awareness needed for adequate functioning under free flight.

In conclusion, many new technologies and operational concepts are being examined for the future air traffic control system. Making intelligent choices will depend on finding systems and concepts that allow both pilots and controllers to maintain situation awareness. Proposed technologies need to be carefully tested to determine potential SA losses or benefits. The use of intermediate LOAs and technologies for reinstating predictability in the system are advocated.

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