Free Flight and Self−Separation

from the Flight Deck Perspective

Sandra Lozito

NASA Ames Research Center

Alison McGann

San Jose State University

Margaret−Anne Mackintosh

San Jose State University

Patricia Cashion

San Jose State University

ABSTRACT

The concept of "free flight" is intended to emphasize more flexibility for operators in the National Airspace System (NAS) by providing more opportunities for aircraft self−separation (RTCA, 1995). The purpose of this simulation was to begin examining some of the communication and procedural issues associated with self−separation in the enroute environment. A simulation demonstration was conducted in the Boeing 747400 simulator at NASA Ames Research Center. Commercial U.S. pilots current on the B747−400 aircraft were the participants. Ten flight crews (10 captains, 10 first officers) flew in the Denver enroute airspace. A new alerting logic designed to allow for airborne self−separation was created for this demonstration. The new flight deck display features were designed and incorporated into the existing navigational display in the simulator to allow for increased traffic and maneuvering information to the flight crew. Each of the flight crews flew eight different scenarios representing different conflict types in the Denver enroute airspace. The effects of traffic density (high and low) and the introduction of an "almost intruder" (AI) aircraft were assessed. Loss of separation was assessed as a safety metric. Timing variables and maneuver strategies were examined to determine potential differences in efficiency of navigation in free flight based on scenario and conflict type. Data analyses on crew procedures revealed few findings associated with traffic density; however, the AI scenario suggested some relationship between display changes for alert levels and self−separation procedures. The impact of these findings on free flight procedural definitions and the identification of future work are discussed.

The concept of "free flight" is a new operational concept that emphasizes more flexibility for operators in the airspace system. Free flight emphasizes a more strategic management of airspace by the various users (e.g., pilots, controllers, dispatchers). Some of the goals for the free flight program include more system efficiency, more collaboration between air carriers and the air traffic system personnel, and pilot involvement in separation responsibility. In order to help define this concept and its viability, the RTCA has published a document defining some of the required technology, procedures, and progressive steps towards the goal of more user flexibility (RTCA, 1995).

The implementation of free flight has many implications for operating procedures. One representation of procedural change is the opportunity for more aircraft self−separation. While it is important to note that the controller will retain final responsibility for separation, aircraft may be allowed more maneuvering flexibility, including increased opportunities for self−separation. Although there is debate surrounding these issues, the availability of self−separation will be affected dramatically by the communication, navigation, and surveillance (CNS) equipment for the ground and aircraft. Also, human factors performance parameters for system users must be considered and assessed. Pilots, controllers, and dispatchers will be impacted by the technological and procedural changes that will accompany the transition towards free flight and the increase in the opportunities for aircraft self−separation.

Several recommendations and assumptions are provided by the RTCA to allow for early free flight implementation, especially those associated with the tasks related to increased opportunities for operational flexibility. Many of these assumptions pertain to technology and procedural changes in airspace operations. One requirement is an increase in navigation and surveillance capabilities available for aircraft to help perform the task of self−separation, and a possible solution suggested by many in the aviation community is Automatic Dependent Surveillance (ADS) technology. The ADS System is a service by which aircraft transmit via data link information derived from onboard navigation systems (RTCA, 1992). These data include, at a minimum, three−dimensional position of the aircraft. The capabilities of ADS also may provide a means for data transmission to enable aircraft self−separation in certain environments.

In addition to the increase in CNS data, some tools associated with automated conflict detection need to accompany the transition to more flexible airspace operations (RTCA, 1995; Paielli & Erzberger, 1997; Yang & Kuchar, 1997). The tools will need to be both ground−based and aircraft−based to permit conflict detection and resolution for the controllers and pilots. (Because this work represents a flight−deck perspective of self−separation, this paper will not address the ground conflict probe.) For the aircraft, the conflict logic will need to exchange data with other surrounding aircraft, possibly using a broadcast capability of the ADS function (ADSB). Data could then be exchanged in an automatic fashion at a rapid rate, transmitting and receiving aircraft performance parameters with aircraft that are similarly equipped. A prototype of aircraft alerting logic has been developed by researchers at Massachusetts Institute of Technology (Yang & Kuchar, 1997).

In addition to conflict detection tools, the data generated by the conflict logic will require an aircraft display for the depiction of the relevant traffic and conflict information. The flight deck display would be able to portray traffic within the range of the ADS−B capability. This display would assist the pilots in the identification and evaluation of traffic and maneuvering issues. In combination, the potential for increased CNS data, the aircraft conflict alerting logic, and the aircraft traffic display may enable an increase in user flexibility in maintaining self−separation within a given environment.

The existence of airspace zones associated with individual aircraft is also suggested as a means to accomplish progress towards a free flight implementation. These zones around aircraft would be represented in the airborne alerting logic to help determine the probability of conflict. Similar to the concept of aircraft zones represented in Traffic Alert and Collision Avoidance System (TCAS) logic, a system currently available on many aircraft designed for collision avoidance, these additional zones define regions around aircraft that serve as a buffer for collision protection. There are two zones discussed in the free flight concept implementation: the protected zone and alert zone (RTCA, 1995). The protected zone is a representation of the current operational separation standards that exist in the domestic enroute airspace. In the domestic United States, five nautical mile (nary) lateral separation and one or two thousand feet vertical separation between aircraft is required in the enroute environment, with the vertical separation varying depending on the altitude of the operations. For the purposes of future requirements and technological advancement, it is assumed that one thousand feet vertical separation will soon be adequate for most of the enroute altitudes. This will be the only predicted modification to the existing separation standards. The protected zone, therefore, is expected to remain free of other aircraft.

The alert zone is a more unique conceptual space associated with free flight and will also be defined around an aircraft. It is larger than the protected zone, as it is intended to permit a preview of potential traffic situations, and to allow for worst−case human and systemic responses (RTCA, 1995). This definition of this zone will be influenced by aircraft equipage and performance characteristics as well as reflect human performance activities associated with aircraft self−separation. Due to the nature of these parameters, the alert zone will be a time−based zone rather than a distance−based zone. A comprehensive identification and definition of required human performance parameters based on self−separation tasks is not yet available; therefore, the alert zone is not yet thoroughly defined.

There has been some speculation that the pilot task of self−separation may be negatively affected by the amount of other aircraft (traffic density) in a given airspace. As an early exploration, an initial full−mission exploration of flight deck issues associated with free flight was conducted by NASA Ames in Fall 1996. An attempt was made at defining and developing some of the technology and procedural assumptions for aircraft self−separation. These included ADS−B data assumptions, the development of a prototypic airborne alert logic (Lee and Kuchar, 1997), and the development of a prototypic aircraft display of traffic. Flight crew participants were asked to fly different enroute scenarios with varying conflict types. After participating in the demonstration, the participants were asked to provide feedback regarding the task of self−separation and the workload associated with that activity. Most of the flight crew participants did not feel that the task of self−separation (as portrayed in the demonstration) represented high workload. However, many suggested that if there was an increase in traffic density in the relevant airspace, their workload may increase significantly. As yet, there has been little or no research examining the effects of traffic density on flight crews in a self−separation environment.

The purpose of this full−mission simulation was to begin examining some of the communication and procedural issues associated with aircraft self−separation in the enroute environment. Particular emphasis was given to the new communication and maneuver procedures represented within the implementation of free flight. The research will help to create early definitions and assessment of some of these procedural and communication issues, with the goal of providing data for consideration in the alert zone definition. Additionally, due to concerns expressed by flight crew participants in the previous demonstration, traffic density was manipulated in an attempt to assess its particular effects upon the task of self−separation.

Method

Participants

Ten crews, consisting of both captains and first officers from two major US airlines flew the Boeing 747400 (B747−400) simulator located at NASA Ames for this study (see Sullivan & Soukup, 1996, for a description of the simulator). Two of the crews were mixed; that is, each crewmember flew for a different airline. Each member flew in their normal crew position. All participants were either current on the B747−400, or retired for not more than six months. Participants had a mean total flight time of 14,545 hours and a mean total flight time on the B747−400 of 1,496 hours.

Design

Each crew participated under two levels of traffic density: low (7 to 8 aircraft) and high (15 to 16 aircraft). Crews flew four scenario types, each in low and high density, with varying conflict geometries (lateral and vertical intruders). An intruder was an aircraft whose path was designed to create a conflict. Lateral conflicts also varied as to which aircraft had the right−of−way. There was also a scenario type in which an aircraft passed close to the ownship, but did not trigger the alert logic.

Airborne Alerting Logic

All traffic and display features were depicted on the navigation display (ND) available to each crewmember. The display was supported by an airborne alerting logic designed for this study (Yang & Kuchar, 1997). This airborne alerting logic overlaid the simulator's Traffic Alert and Collision Avoidance System (TCAS) logic. TCAS involves immediate tactical conflict avoidance whereas the airborne alerting logic was designed to help crews manage self−separation more strategically. The goal was to create a seamless relationship between the airborne alerting logic and TCAS (see Figure 1). Therefore, TCAS was left intact with the exception that the first two threat levels of display symbology (unfilled diamond and filled diamond) were replaced with the experimental display symbology. The yellow circle for a Traffic Advisory (TA) and a red square for a Resolution Advisory (RA) were still available. Currently, the TCAS display depicts surrounding traffic at approximately 40 nm from the ownship. In contrast, the alerting logic in this study extended traffic depiction out to 120 nm in front of and to each side of the ownship (the participating crews' aircraft) and 30 nm behind the ownship. This range was based on the surveillance capabilities that may exist in ADS−B technology. An altitude filter limited the vertical range of viewable traffic. Like TCAS in the neutral configuration, traffic in a non−alert state was visible 2700 feet above and below. Traffic in an alert state was visible up to 3400 feet above and below. Flight parameter information was transmitted via a simulated Automatic Dependent Surveillance Broadcast (ADS−B) technology.

Cockpit Display of Traffic Information

Traffic was represented by the symbol "V" with the apex indicating the aircraft's direction. Altitude (relative to ownship or absolute altitude) along with the callsign were displayed next to each traffic symbol. All traffic was initialized at Alert Level 0 (AL0) indicating no threat. The traffic symbol changed based on the predicted threat level. These predicted threat levels corresponded to several alert levels present in the logic. As the probability of conflict rose, the aircraft transitioned through various alert levels. The alert levels ranged from Alert Level 1 (AL1) that indicated a threat, AL2 indicated an increase in threat, to AL3 or "alert zone transgression." An alert zone transgression was the condition in which the logic predicts a pending violation of the protected zones of the aircraft at a higher probability level (see Yang & Kuchar, 1997, for a description of the logic). Operationally, the alert zone transgression was the point at which intervention may be required (RTCA, 1995). Figure 1 shows how a pending conflict could progress if evasive maneuvers were not taken.

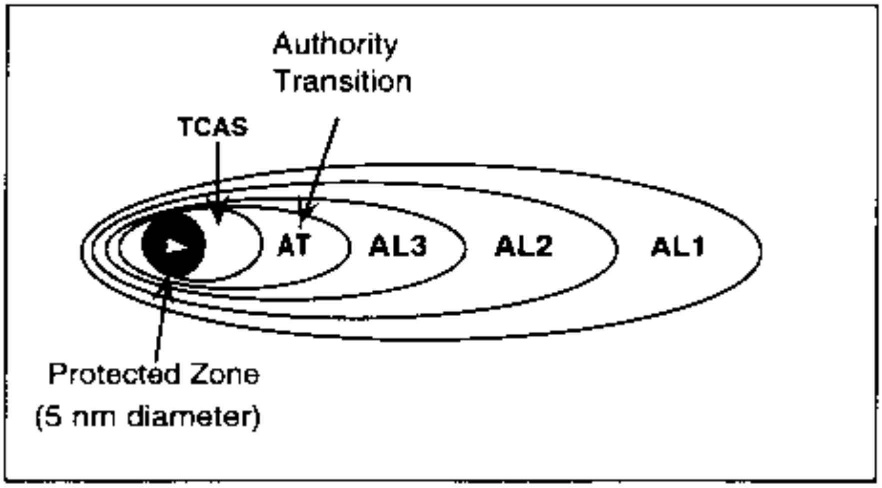


Figure 1. This diagram represents conceptual alert zones surrounding an aircraft (adapted from Yang & Kuchar, 1997)

Figure 2 illustrates the display changes associated with alert level for the intruder. AL1 was indicated by a blue traffic symbol and a blue ID and altitude tag. If the situation progressed, AL2 was displayed, and the "V" filled in with the color blue changing the symbol from a "V" to a triangle. AL3, or "alert zone transgression", was indicated by the following display changes: 1) A line extending from *both* the ownship and the intruder symbol. At the end of each line was a circle that represented the current separation standard of 5 nm in diameter. Any overlap of the circles indicated impending loss of operational separation; 2) An aural warning "Alert" sounded twice; 3) The word "ALERT" appeared on the lower right hand comer of the display, along with the intruder's call sign and the time to closest approach. The time to closest approach was the time remaining before aircraft were projected to pass in closest proximity to each other on current flight paths.

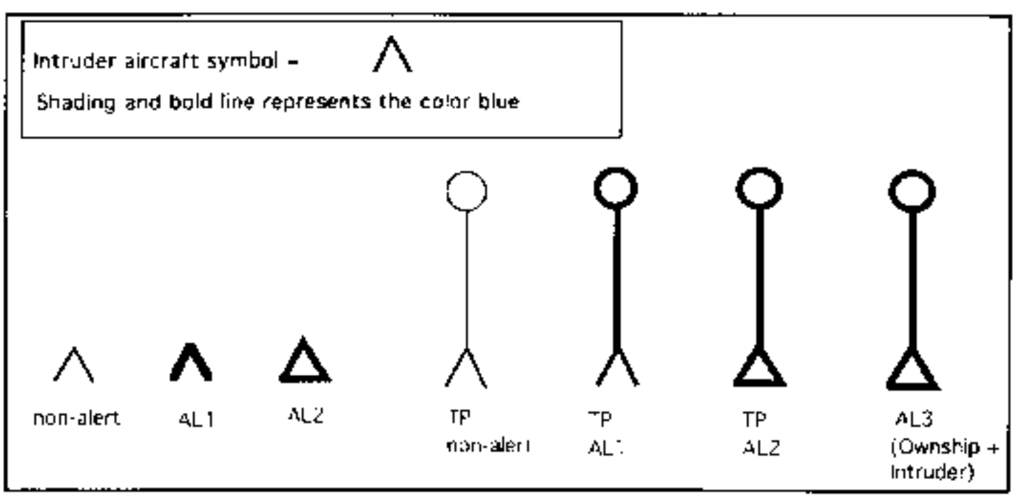


Figure 2. Intruder aircraft display features associated with alerting levels and temporal predictors.

If no evasive maneuvers were taken, AL4, the Authority Transition point was reached. AL4 represented an increased threat beyond AL3 and was visible only to the controller. At AL4, the confederate controller was instructed to query the crew about their proposed solution. If the crew was not in the process of resolving the conflict, the controller was instructed to cancel free flight and issue a maneuver instruction. As crews solved a conflict, the alert levels degraded. This provided crews with feedback on the success of their solution. For example, if crews selected a left heading change in AL2, AL2 would degrade to AL I as the threat probability was reduced, and finally no threat (ALO) was displayed.

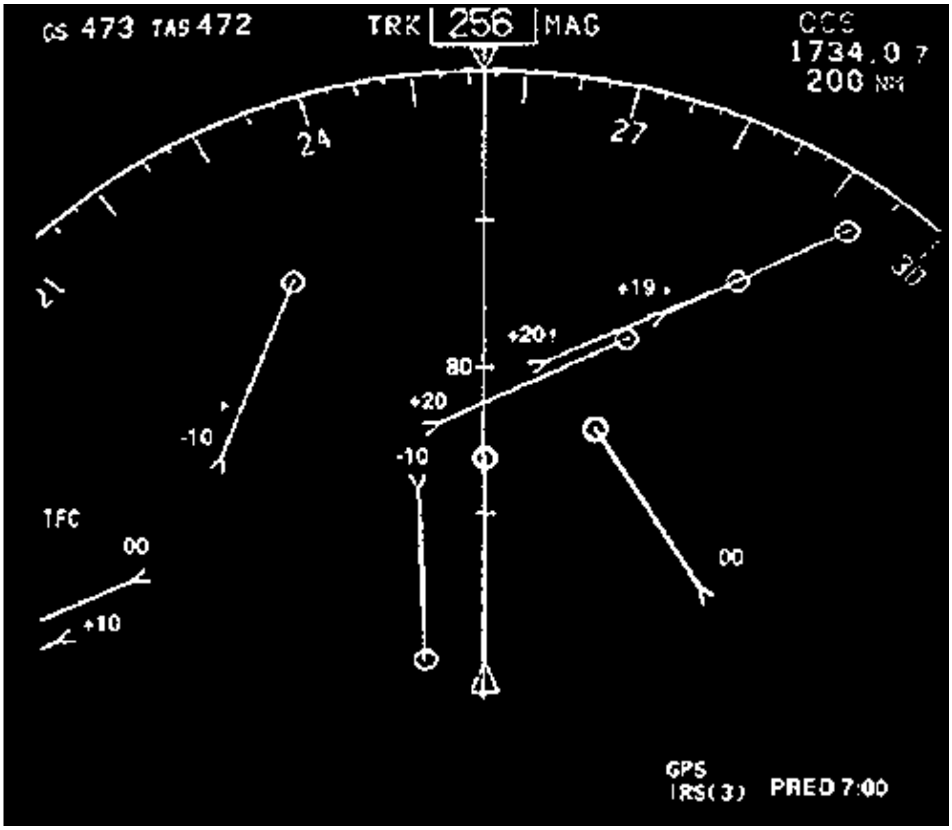


Figure 3. Navigation Display (ND) showing traffic and temporal predictors.

Selectable Display Features. Crews could select display features designed to aid them in self−separation. Selectable display features could be manipulated by a small box mounted above the Mode Control Panel. Crews could reduce clutter by toggling a button to de−select the traffic callsigns. Another selectable feature was the temporal predictor. The predictor relied on ADS−B data and not on data derived from the flight management system. The predictor provided crews with estimation, based on current aircraft state information, of where other aircraft would be relative to the ownship for selected time intervals in one minute increments. With the predictors, crews could determine which aircraft might create a potential conflict prior to an alert level indication. When predictors were selected, they were displayed for all aircraft. The predictor symbol was identical to the shape of the AL3 symbology with a line and a circle that represented 5 nm in diameter. When selected, predictors were depicted for the ownship and for all other traffic symbols (see Figure 3). The predictor symbology was white when no aircraft were in an alert state. However, predictor symbology reflected color changes associated with alert level changes for those aircraft in an alert state. The predictor could be selected at a time interval that ranged from 0to 10 minutes. Selected predictor time was displayed at the lower right hand corner of the ND. Also, to reduce clutter, predictors and callsigns of the non−conflicting traffic were automatically cleared from the display at AL3 but could be reselected at any time. Finally, crewmembers could also de−clutter the ND by changing the horizontal map range. Ranges available were the same as those available on the ND of the B747−400 (10, 20, 40, 80, 160, 320, and 640 nm).

Procedure/Task

Crews were briefed about the general goals of the free flight concept and of the study. The briefing emphasized the increased operational flexibility possible with free flight. After the briefing, crews received approximately one and a half hours of training in the B747−400 simulator. The training involved flying scenarios, and included discussion of the display features, rules of the road, and other task components. These training scenarios were different from the actual experimental scenarios.

Each crew flew eight cruise segments from a starting point over Denver airspace toward one of two destinations, John F. Kennedy (JFK) or San Francisco International (SFO) airports. Prior to the start of each run, crews were asked to enter an FMS route that included departure airport, two waypoints and a destination airport. The crews were positioned at optimum altitude and airspeed given their current gross weight, and no winds or turbulence were present. Although crews were told the approximate duration of the scenarios, they were instructed to assume that they were going to arrive at their destination (JFK or SFO). Crews were told that they could maneuver and change any of their flight parameters during any point during the flight, but to keep fuel efficiency and time to destination in mind. The crews were informed that all aircraft in their vicinity had similar equipage and were on the same frequency and that ATC was also on the same frequency. They were informed that they could communicate with other aircraft and with ATC, but were not required to do so at any time. They were advised that the controller could intervene at the Authority Transition point and that the controller still retained ultimate separation responsibility.

Scenarios. Each crew flew a total of eight different scenarios which ranged in duration from 10 to 20 minutes. Every crew flew a low and high density version of four scenario types. The conflicts in the high and low density versions of each scenario type were identical, with the only differences in scenarios being that the aircraft had different call signs and different levels of non−conflicting traffic were represented. The intruders intersected the ownship flight path either laterally or vertically. One of the four scenario types included a lateral conflict in which the ownship had the right−of−way (i.e., ownship was on the right). The second scenario type included a lateral conflict in which the ownship had maneuvering responsibility (i.e., intruder was on the right). For both the lateral scenario types, the intruder and ownship were initialized 16 minutes away from an impending collision provided no maneuvers were taken. A third scenario type included a vertical conflict in which the intruder descended into the ownship's flight path. Because of the altitude filter, the intruder appeared in the scenario at AL 1 at 3400 feet above the ownship and in a descent. It quickly progressed to AL3 in about 3−5 seconds. For this scenario type, an impending conflict was set to occur 9 minutes from the start of the scenario. It was impossible for the crews to detect this intruder prior to an alert state because of the altitude filter. This could have affected a difference in the maneuvers and conflict solutions the crews selected compared to the lateral conflicts. In the final scenario, the intruder passed closely in front of the ownship (7−8 miles) but did not trigger any alert (the AI scenario). The intruder was initialized to pass in front of the ownship at approximately 7 minutes from the start of the run. If no maneuvers were made in this scenario, the two aircraft would not have lost separation.

Rules of the Road. The lateral scenario types also varied by right−of−way considerations. According to the recommendations of the RTCA, the crews were instructed to determine who should maneuver by the current VFR rules of the road (ASA, 1997). In one of the two lateral scenario types, the intruder approached the ownship from the left, and in one it approached from the right. The rule that applies to these scenarios state that when two aircraft are laterally converging the aircraft on the right has the right−of−way and the aircraft on the left should maneuver. The altitude scenario type involved an aircraft that descended through the ownship's altitude vertically and was positioned to the right of the ownship laterally. The current VFR rules of the road do not specify who has the right−of−way in an altitude conflict. Although some crews from the previous study suggested that the aircraft with a stable altitude should have right−of−way, the crews were not provided with a rule for this case. How the crews interpreted the right−of−way in this scenario was of interest.

Communications/Negotiations. Two confederates assisted in the communications and negotiations with the ownship. One person generated partyline communication and the other played the part of the intruder and ATC. The confederates were instructed to respond to calls from the ownship but not to initiate calls. The confederate pilot was instructed to maneuver if requested when the ownship had the right−of−way. When the intruder had the right−of−way, the confederate crew would maneuver if requested on the second contact from the ownship. Partyline communication consisted of requests for information such as turbulence reports and current flight parameters. There were no air−to−air negotiations available over partyline. The frequency congestion (partyline) was equal for both traffic density conditions.

Results

Safety

Self−separation. One safety measure collected was the pilots' ability to maintain adequate separation between themselves and the other traffic. Adequate separation was defined as either 5 nm laterally or 1000 feet vertically. In all but one of the 80 runs, separation was maintained. The single loss of separation occurred in a low density, lateral scenario type in which the ownship had maneuvering responsibility. The distance at the closest point of approach between the ownship and intruder was 4.86 nm.

Density

Maneuvers. Separate analyses were conducted comparing the frequency of maneuvers in the high and low density conditions for each scenario type. For the AI scenario, a significant difference was found for the number of ownship maneuvers between the high and low density conditions, $\chi^2(1)=3.81$, $p=.05$. Five of 10 crews maneuvered to avoid the intruder in the high density condition, while one of 10 crews maneuvered in the low density condition. For the three remaining scenario types, no differences were found. (See the right−of−way discussion below for further discussion of ownship maneuvers.)

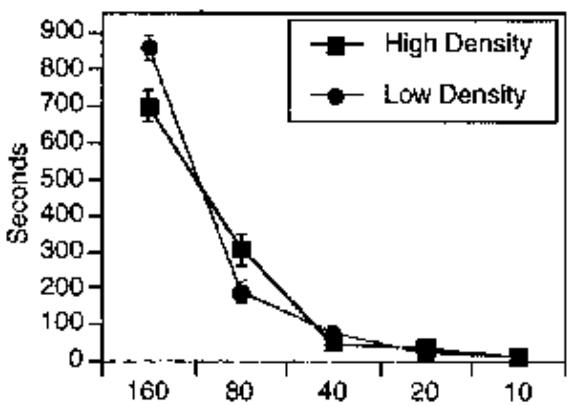
Use of Map Range. A separate 2 (Density) x 5 (Map Range) repeated measures Analyses of Variance (ANOVA) were conducted comparing the total time spent at each map range (seconds) for each of the four scenario types. Because little or no time was spent at the 320 nm and 640 nm map ranges, these ranges were not included in the analyses. Thus, all analyses were conducted on the 10, 20, 40, 80, and 160 nm map ranges. Three Density x Range interactions were found, one for the lateral scenario type with the right−of−way, one for the lateral scenario type without the right−of−way, and one for the AI scenario type (see Table 1 for ANOVA results). A main effect for range was found for the altitude scenario type.

All three Density x Range interactions indicated that more time was spent at the larger 160 nm map range in low density conditions than in high density conditions. Conversely, more time was spent at the smaller 80 nm map range in high density conditions compared to the low density conditions (see Figures 4a−c). This pattern was the same for both of the lateral scenario types and the AI scenario type. For the altitude scenario type, the altitude filter prevented the intruder from appearing on the display until already in an alert state. In this scenario type, there was a main effect for map range with more time spent at the higher map ranges (160 and 80 nm, see Figure 4d). Across all four scenario types, crews spent more time at the 160 nm range, followed by the 80 nm range with relatively little time being spent at the lower ranges (10, 20, and 40 nm).

Table 1. Results from Density x Map Range ANOVAs.

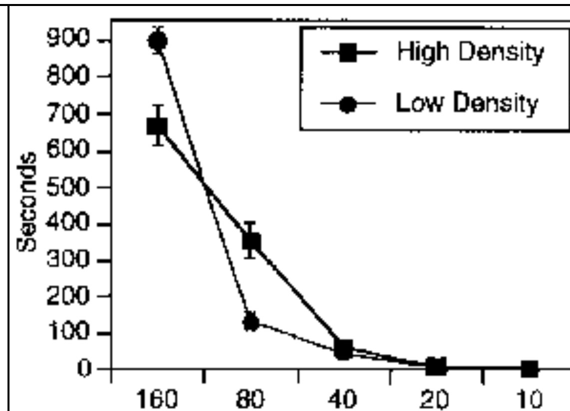
Lateral with ROW *	Density x Range	F(4,76)=13.64	p < .001
Lateral without ROW*	Density x Range	F(4,76)=12.75	p < .001
Almost Intruder	Density x Range	F (4,76)=6.82	p < .001
Altitude	Range	F (4,76)=118.38	p < .001

* Right−of−Way



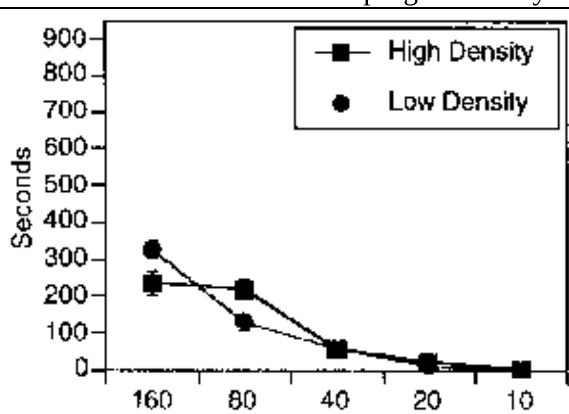
Selected Map Range (nm)

Figure 4a. Time on map ranges for lateral scenarios with ownship right−of−way.



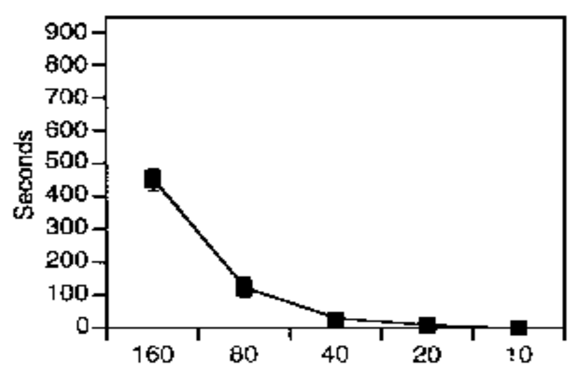
Selected Map Range (nm)

Figure 4b. Time on map ranges for lateral scenarios without ownship right−of−way.



Selected Map Range (nm)

Figure 4c. Time on map ranges for Almost Intruders scenarios



Selected Map Range (nm)

Figure 4d. Time on map ranges for Altitude Intruders scenarios

Right−of−Way

Maneuvers. For the lateral scenario types, when the ownship clearly had maneuvering responsibility (i.e. intruder was on the right), the ownship maneuvered in 20 of 20 runs. In three of the 20 runs, the intruder also maneuvered in coordination with the ownship. For the lateral scenario type in which the ownship had the right−of−way (i.e. the ownship was on the right), the ownship maneuvered in six of 20 runs (three in the high density and three in the low density condition). In four of 20 runs, the intruder also maneuvered in coordination with the ownship. For the altitude scenario type, in which the right−of−way is ambiguous, the ownship maneuvered in 10 of 20 runs. In one of 20 runs, the intruder maneuvered in coordination with the ownship. As previously mentioned, the ownship maneuvered in six of 20 runs in the AI scenario type.

Analyses of Maneuvers

Number of Parameters. Crews could use up to three parameters (speed, heading and/or altitude) to resolve a conflict. Table 2 provides frequencies for the number of elements used in conflict avoidance. For both high and low density conditions, participants seem to be more likely to use a single parameter in resolving a conflict than multiple parameters.

	1 parameter	2 parameters	3 parameters
High Density	16	5	2
Low Density	15	4	0

Table 3. Parameters used to resolve conflicts in high and low density conditions.

	Heading	*Speed*	Alt
High Density	21	9	2
Low Density	15	6	2

Maneuver Onset Time. For the lateral scenario types, most crews waited until after the first alert level to begin maneuvering (21 of 26 maneuvers). In the altitude scenarios, the intruder entered the scenario already in an alert state. For the AI scenario type, there were no alerts by design. For the lateral scenario type where the ownship has the right−of−way, a paired samples test was conducted on maneuver onset time. Maneuver onset time was defined as the time from which the intruder first appeared in the scenario to the onset of the first maneuver. No effect was found for density, $t(9) = -1.72$, p = n.s. No timing analyses were conducted for the lateral scenario type where the intruder had the right−of−way, the altitude scenario type, and AI scenario type because there were so few ownship maneuvers.

Fuelburn. A fuelburn analysis was conducted for the lateral scenarios in which all crews maneuvered (lateral without right−of−way). Actual fuelburn was added to an estimated value which calculated fuelburn from the ownship's position at the end of the run to the next waypoint. This allowed for a consistent comparison across crews. A paired sample t−test showed no significant differences in the amount of fuel burned between the high and low density conditions, $t(8) = .17$, p = n.s. As the majority of maneuvers included heading, there were not enough maneuvers with each parameter, or combination of parameters, to allow an analysis of fuelburn based on maneuver type.

Analyses of Communication

Air−to−Air Communication. Most crews contacted the intruder aircraft. For the lateral scenario type in which the ownship had maneuvering responsibility, crews contacted the intruder in 17 of 20 runs. For the lateral scenario type in which the ownship had the right−of−way and the altitude scenario type, the crews contacted the intruder in every run. However, in the AI scenario type, the crews contacted the intruder only in 7 of 20 runs. There were no differences based on density.

For the lateral scenario types, the time at which the crews initiated contact with the intruder in relation to the alerting levels was investigated. Crews contacted the intruder before the first alert level in only 2 of 37 runs in which communication was initiated. In the altitude scenarios, the intruder entered the scenario already in an alert state and quickly progressed to an alert zone transgression. Therefore, all communication occurred after the alert zone transgression. For the AI, the intruder did not pass through any alert levels.

Air−to−Ground Communication. Communication with ATC initiated by the participants was infrequent occurring in only 14 times in 80 total runs.

Discussion

This full−mission simulation study attempted to uncover issues surrounding flight crew procedures in a self−separation environment. In investigating different conflict types in low and high traffic density conditions, the possible impact of traffic density upon flight crew participants was explored. Communications and maneuvering procedures were examined within the two traffic density conditions.

Safety

There was one dependent measure collected as a safety parameter: aircraft separation. Of the 80 total scenarios flown as part of this simulation, there was a loss of operational separation in one scenario. This was a horizontal separation loss that occurred in one of the lateral scenario types. The participant crew appeared to be heading back on course and turned back too early. Also, the crew had used several lateral maneuvers for avoidance during this scenario, and perhaps underestimated the required heading change. In the remaining 79 scenarios considered for data collection, vertical and horizontal separation was maintained.

Density

Most of the data evaluated in this study do not indicate performance differences between the low and high traffic density conditions. With some exceptions, there were no significant differences for communication or maneuvering procedures based on the traffic density manipulation. The differences in amount of traffic depicted in the two conditions may not have been sufficient to create dramatic differences in performance; however, the traffic volume and patterns were representative of the relevant Denver Center sector during a moderately high traffic period.

The data associated with the map range may provide valuable insight into the general lack of performance differences between the low and high density conditions. The use of the range selection for the pilots offers an opportunity to visually manage the density of traffic depicted on their ND. The ADS−B range portrayed traffic on that display within approximately 120 nm in front and to the side of the ownship. Although the participants most often selected the 160 ND range, they were more likely to use a range of 80 nm on the ND in high density than in low density (in low density they were more likely to select 160 nm). When compared to a larger range, the reduced range (80 v. 160 nm) magnifies the display features available, perhaps giving better information about aircraft in close proximity and their relevant position. Although this range selection reduces the opportunity to see traffic as early as possible (since it no longer includes the 120 nm ADS−B range), it does provide a more detailed view for a more limited range, and appears to be desirable for the high density conditions. It also has the advantage of "screening out" traffic that is further away and is therefore less likely to be of immediate concern to the participants. However, this range reduction has the potential costs of missing early indications of potential intruder situation.

There are at least a few other possible explanations for the density findings. It may be that the traffic density effects upon the flight crews' ability to self−separate are negligible. The context of this simulation study is important: the participants flew scenarios within the enroute environment under normal operations (i.e., there were no abnormal situations). This is a fairly low−workload environment for the crews, perhaps enabling them to devote more attention to the associated self−separation tasks than under other circumstances. In current carrier operations, however, the enroute flight phase is considered to be a fairly low−workload environment, assuming no abnormalities exist (including weather, which also was not represented in this study).

Another possible explanation for these findings may be related to the availability of escape maneuvers in the two density conditions. In order to be consistent, the high and low density scenarios for each of the conflict types had access to the same escape maneuvers. Thus, when the intruder was approaching from a particular direction, the participants had the same opportunities to maneuver the aircraft and avoid the conflict in both the low and high density conditions (at least the three escape maneuvers of heading, speed, and altitude were available per scenario). This may have mitigated the potential workload differences between the two conditions. Even in the scenarios in which the participants did not maneuver, the presence of different escape routes may have made the conflict appear manageable from the flight crew's perspective.

The one scenario type in which traffic density differences did exist was the AI. While no alert logic is triggered for the intruder, the aircraft appears to be in close proximity to the ownship aircraft on the ND. The requirement for vigilant monitoring may actually be higher in this case than in the cases in which the display features are triggered. Despite the fact that the logic does not trigger an actual alert, the intruder appears close to the ownship on the display, and is moving closer as the scenario progresses. A certain amount of perceived uncertainty and anticipation of a pending alert situation may exist for the participants. In a high density condition, the crews were more likely to maneuver, therefore alleviating the monitoring requirements associated with the AI due to the larger amount of traffic. Additionally, if the application of the right−of−way rules is assumed to be related to an alert condition, there may be more confusion about maneuvering procedures when the logic does not indicate an existing conflict. In fact, the near−conflict has the ownship on the right, so maneuvering responsibility could have been assumed to be the intruder's. However, the overall lack of clarity in this event could result in the participants assuming maneuvering responsibility to efficiently handle the situation through early avoidance of a potential conflict.

Communications

Another interesting finding in this study is the data indicating the high likelihood of intercrew communication. It was very common for the participants to contact the intruder aircraft at least once. The function of that communication with the other aircraft has yet to be examined. It is also interesting to note that the findings for the AI scenario were unique with regard to the intercrew communications as well. The crews in the AI event were less likely to contact the other aircraft when compared to the other scenarios, perhaps because the logic had not indicated a conflict. Again, the alerting logic, and /or the display feature changes associated with it, appear to signal the beginning of the self−separation procedures for the flight crew. For the overall intercrew findings, these data may lead to frequency congestion concerns if the voice channel is used for free flight communications.

Maneuvers

The procedural considerations associated with VFR right−of−way rule interpretation are revealed in some of the findings in this study. There were a total of 40 scenarios (across all participants) in which the VFR right−of−way rules for lateral conflicts could be applied directly. In those events, the aircraft on the right is assumed to have the right−of−way (i.e., does not have the requirement to maneuver). There were some differences in the type of maneuvering decisions made by the flight crew participants, and these differences were also related to interpretation of the VFR right−of−way procedures. This guideline was followed consistently when the participants did not have the assumed right−of−way (20 out of 20 times the ownship maneuvered), and less consistently when they did have the right−of−way (6 out of 20 times the ownship maneuvered). Thus, even when the right−of−way interpretations clearly indicated that the maneuvering responsibility belonged to another aircraft, the flight crew participants often still maneuvered. The uncertainty of conflict resolution when depending on another flight crew may lead them to assume the responsibility and regain some early control of time and maneuver efficiency.

Finally, there are some data suggesting a preference in the types of aircraft maneuvers used by the participants during conflict avoidance. There were three aircraft performance parameters considered for these analyses: heading, speed, and altitude. Most often crews used a single performance parameter to maneuver. It is assumed that this finding is based on the desirability of keeping maneuver actions and maneuver evaluations simple. Also, there does seems to be an overall preference related to the frequency of use of a particular parameter. Specifically, heading changes were used most often for conflict resolution, then speed changes, then altitude changes. There are a few possibilities that could explain these preferences. The traffic display is a 2−D display which may make heading changes easier to evaluate. Additionally, the aircraft was configured such that the optimum altitude was also their cruise altitude during the scenarios. Modifications to the altitude parameter may have been interpreted as not beneficial due to their aircraft weight and speed. Finally, speed maneuvers require a fairly long time to take effect, possibly discouraging the use of that parameter for conflict resolution. It is important to note that this analysis does not consider the magnitude of the maneuvers, but rather the frequency of their use. Also, the relatively low frequency numbers across two of the three parameters prevents any true fuel efficiency comparisons between these parameters across similar scenarios. For example, speed and altitude were rarely used for maneuvering.

General conclusions and summary

This simulation represents an early attempt to define and describe some of the procedural concerns for the flight crew in a self−separation environment. Since the study is one of the first simulations to try to determine these issues in a full−mission context, its primary goal was to gather some baseline data from which to define future research issues. Much more work needs to be accomplished to help thoroughly define and evaluate the implementation of free flight and the concept of pilot self−separation. There are several pertinent human factors concerns that were not addressed in this simulation. First, the controllers in the simulation were confederates of the researchers. Their behavior was scripted and could not reflect controller performance in an aircraft self−separation task. The impact of the introduction of controller participants within this context is unknown, but it is expected that it would have an impact on many variables (e.g., the time allowed for conflict resolution). For example, although limited traffic density differences were found in this study, previous work suggests that amount of traffic does have an impact on controller performance (Hilbum, 1996). Additionally, when the flight crew participants contacted the other aircraft, the "pilot" with whom they spoke was a research confederate. Such issues as air carrier procedure differences or competition between carriers were not represented in this simulation due to this methodological constraint. Finally, there were no weather situations in any of the scenarios It seems clear that a variety of weather concerns could result in a much more difficult self separation task due to such considerations as required course changes, display configuration, and display clutter issues. For example, the presence of weather may have made it more difficult to manage clutter in the high density condition. The crews may be more reluctant to reduce display range if this results in a loss of weather information available at a longer range selection.

This simulation has provided early insight into some of the important self−separation concerns. The data from this study suggest that air−air communications will be critical, air−to−air. In addition, these findings indicate that the particular concerns associated with alerting logic and the application of procedures needs to be explored. These results also helped identify some of the maneuvering procedures that may exist in a self−separation environment. Although the conditions present in this simulation were not worst−case, baseline data were derived to assist in early free flight concept definition. As this concept develops and the research findings accumulate, the human performance concerns must continue to be defined and assessed for all users of the airspace system.

References

Aviation Supplies and Academics. (1997). Federal Aviation Regulations Airman's Information Manual. Renton, Washington: Aviation Supplies and Academics.

Hilburn, B., Jorna, P.G.A.M., Byrne, E.A., & Parasuraman, R. (1997). The effect of adaptive air traffic control (ATC) decision aiding on controller mental workload. In M. Mouloua, & J. M. Konce (Eds.), Human automation interaction: Research and practice, (pps. 84−91). Mahwah, NJ: Erlbaum.

Paielli, R. A., & Erzberger, H. (1997). Conflict probability estimation for free flight. Journal of Guidance. Control. and Dynamic, 20(3), 588−596.

RTCA. (1992). Minimum operational performance standards for airborne automatic dependent surveillance (ADS) equipment (RTCA/DO−212). Washington DC: RTCA

RTCA. (January, 1995). Final report of the RTCA board of directors' select committee on free flight. RTCA, Incorporated, Washington, DC.

Sullivan, B. T., & Soukup, P. A. (1996, July). The NASA 747 −400 flight simulator: National resource for aviation safety research. Paper presented at American Institute of Aeronautics and Astronautics, San Diego, CA (AIAA−96−3517).

Yang, L., & Kuchar, J. (1997). Prototype conflict alerting logic for free flight. (AIAA 97−0220). Reston, VA: American Institute of Aeronautics and Astronautics.