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National Aerospace Laboratory NLR

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Free Flight and the Air Traffic Controller: an exploratory analysis of human factors issues

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Summary

Under mature Free Flight (FF), aircraft outside of terminal areas would generally be permitted to fly their preferred routes, and self-separate, with minimal intervention from air traffic control (ATC). From an ATC perspective, FF could raise a number of human performance problems (including workload extremes, passive monitoring demands, and difficulties in reverting to manual control). This paper describes an empirical evaluation recently carried out at the NLR, in which *Controlled Flight* conditions (analogous to current-day operations) were compared to *Free Flight* for the en-route environment. The simulation specifically manipulated *Intent Sharing* under FF— that is, whether aircraft provided advance notice of their intended manoeuvres. Results showed workload benefits of FF (especially under high traffic). Intent information seemed to increase controllers' acceptance of FF, but had no clear effect on workload. Removal of intent information seemed to bias controllers' conflict prediction performance. Finally, HMI considerations emerged as important ones for future work in this area.

Contents

(30 pages in total)

Glossary

AC	Aircraft
ADS-B	Automatic Dependent Surveillance - Broadcast
AFDOF	Altitude for Direction of Flight
ATC	Air Traffic Control
ATCo	Air Traffic Controller
BSMI	Rating Scale for Mental Effort
CF	Controlled Flight
EFR	Extended Flight Rules
EVOR	Extended VFR Overtaking Rules
FDB	Flight Data Block
FF	Free Flight
FFI	FF with information sharing
FFN	FF with no information sharing
FL	Flight Level
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
MTCA	Medium Term Conflict Alert
NARSIM	NLR ATC Research Simulator
NLR	National Aerospace Laboratory of the Netherlands
PFP	Phase of Flight Priority
PVD	Plan View Display
RSME	Rating Scale for Mental Effort
RT	Response Time (also Radio Telephony)
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
SUA	Special Use Airspace
TCP	Trajectory Change Point
TLX	Task Load Index
VFR	Visual Flight Rules

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1. Introduction

Free Flight (FF) has been proposed as a way to both handle ever-increasing air traffic demands, and to provide economic benefits to airspace users. Although FF has thus far been defined only at a high level (RTCA, 1995), research into FF concepts (e.g., direct routing) is proceeding on both sides of the North Atlantic. According to a vision of mature FF, aircraft outside of terminal areas would generally be free to fly user-preferred routes, and modify their trajectories en route, with minimal intervention by air traffic control (ATC). Although the advent of FF assumes certain enabling technologies (e.g., ADS-B capability, and conflict probe tools), FF would represent as much an operational, as a technological, evolution.

Under likely near-term FF scenarios, the Air Traffic Controller (ATCo) would continue to play an important (albeit new) role in ATC (Hanson, 1997), especially in the face of unpredictable aircraft behaviour. Rather than strategically controlling air traffic, the “controller” of the future might well fill the role of either a strategic flow manager, and/or a tactical “Separation Assurance Monitor,” who would intervene only when losses of separation were imminent. This new role would raise a number of potential human performance problems (e.g., workload extremes, vigilance problems, and reversion-to-manual difficulties). Specific research questions that have been posed include the following:

- How can command authority be dynamically and unambiguously transferred between air and ground?
- How can joint evasive manoeuvres be communicated and negotiated?
- What information will air and ground exchange? Will they withhold any information?
- Must the two sides share intent information? If so, how far in advance?
- What are the workload implications of information uncertainty?
- What happens when equipment fails? Can controllers serve as backups to automated conflict probe / resolution functions?
- Will underloading /overloading present problems (e.g. in terminal areas)?
- Will situation awareness demands present problems?
- What are the best ways to structure computer assistance? What are the best ways to design displays and algorithms, so as to facilitate information sharing between air and ground?
- Are there behavioral bases for defining intervention strategies, airspace structures, resolution time horizons, etc?
- How can issues of liability and responsibility be resolved?
- How should Traffic Flow Management (TFM) handle potential "gaming" of arrival intent information?
- Will pilots / controllers accept the concept of FF?
- How should we select and train appropriate operators?

To understand how profoundly the change to FF could influence controller workload and monitoring, consider the following simple diagram, which depicts the principles of controlled and free flight in the en-route phase. The diagrams are identical, except that the angle of four of the ten aircraft has been changed under free flight. Notice how this complicates the task of anticipating traffic conflicts. Under controlled flight (CF), there are a limited number of areas at which conflicts are likely to occur. Indeed, the historical reasons behind the current-day fixed route structure have to do more with human limitations than with technical or procedural concerns. Under FF, on the other hand, assuring separation of the same number of aircraft seems a daunting task for the air traffic controller.

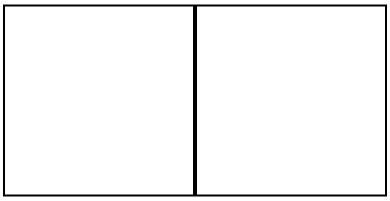


Fig. 1 Controlled versus free flight

A recent experiment by Endsley, Mogford & Stein (1997) assessed the effect of FF-like scenarios on ATCo situation awareness and mental workload. Workload in their study, however, was only assessed in terms of self-reported subjective workload. This paper reviews an exploratory experiment recently conducted at NLR into the effects of similar FF traffic scenarios on ATCo workload, monitoring performance, and ability to anticipate non-nominal situations. This was done by assessing the performance of currently-active controllers under both conventional (i.e. controlled) and free flight conditions, using the same en-route airspace. Two free flight conditions were evaluated: one in which aircraft shared their intentions with ATC before manoeuvring, and one in which aircraft manoeuvred without notifying ATC. In addition to subjective workload ratings, the current study also collected objective (pupil diameter, heart rate variability) measures of mental workload, and measures of controllers' conflict prediction performance.

2. Method

2.1 Air Traffic Controllers

Test subjects were ten United Kingdom Royal Air Force (RAF) military controllers, drawn from both the Glasgow and London regions. Of these, all but two were currently active controllers. The final two controllers had recently been retired from the RAF. Age ranged from 30 to 40 (mean = 35.5 years), and years of active controlling experience ranged from 6 to 22 (mean = 11.9).

2.2 Operational Concept of Free Flight

Free flight is an evolving concept. Nonetheless, before an exploratory evaluation of FF could be carried out, some basic definition had to be made of the operational scenario in which aircraft would operate. This definition had to specify how aircraft would behave, including: how aircraft would self separate ("rules of the air”); how to handle ambiguous air-ground relationships; rules for non-nominal situations; and airspace-specific procedures that would accompany FF.

The cornerstone of the employed ATM concept was a set of "Rules of the Air," or Extended Flight Rules (EFRs), that could be used to conduct free flight simulations. EFRs were intended to dictate how aircraft should self-separate, under conditions of minimal (or no) ground intervention. They had to do so both comprehensively (i.e., for all possible traffic encounters) and unambiguously (i.e., each party had to have a clear understanding of the responsibilities of all aircraft). Further, to expedite pseudopilot training, it was decided that the number of extended flight rules had to be kept to an absolute minimum. EFRs were based upon reviews of the following sources:

- The set of EFRs based on extensions of the standard ICAO VFRs (e.g., "overtake on other ship’s starboard side") specified by Duong, Hoffman, Floc’hic and Nicolaon (1996) to guide EUROCONTROL free flight simulations.
- The air separation rules specified in the ATLAS framework (ATLAS v2.3 Annex 7), to guide the exploration of autonomous self-separation.
- The operational concept of Endsley et al (1996), who conducted free flight simulations using realistic US en route airspace.

The EFRs used some simplifying assumptions for the purposes of experimental design. For instance, these EFRs disregard such factors as: model-of-aircraft differences in manoeuverability; gross mismatches in aircraft equipage; and flight priority differences.
The following paragraphs provide information on the selected EFRS.

2.2.1 Rule 1: Altitude for Direction-of-Flight (AFDOF)

According to this rule (which is based directly on IFR cruising altitudes), aircraft are required to fly at alternating flight levels determined by their heading, and separated by a minimum of 1,000 feet (i.e., 10 FLs). On headings of 360 (i.e., due north) to 179 degrees, aircraft must fly at odd numbered Flight Levels (FLs). On headings of 180 (i.e., due south) to 359, aircraft must fly at even numbered FLs. For example, eastbound aircraft may operate at FLs 170, 190, 210, 230, etc. Westbound aircraft may operate at FLs of 160, 180, 200, 220, etc. These rules apply to cruise only and not to the transitional phases of flight.

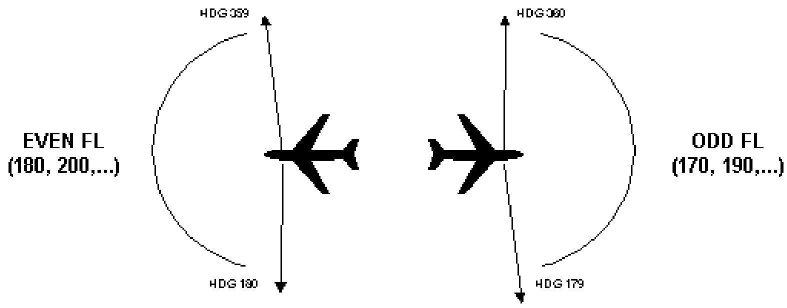


Fig. 2 Altitude for Direction-of-Flight (AFDOF) rule

2.2.2 Rule 2: Phase-of-Flight Priority (PFP)

Differences in phase-of-flight (e.g., climb, cruise, descent) are associated with differences in aircraft manoeuvrability. It was decided that this should be reflected in the determination of which aircraft should bear the greater responsibility for evasive manoeuvring. Duong, Hoffman, Floc'hic and Nicolaon (1996) developed a matrix of priorities for aircraft in encounter situations, based on both the phase (i.e., climb, cruise, descent) of each, as well as the sub-phase (e.g., initial, intermediate, final sub-phases of climb). It was decided that such a fine categorisation would have been impractical to implement with experimental test subjects. Therefore differences in sub-phase were disregarded. As a result, the following matrix of Phase-of-Flight Priority (PFP) has been used in the experiment. As shown in figure 3, for example, a cruise AC has priority over either a climbing or a descending AC.

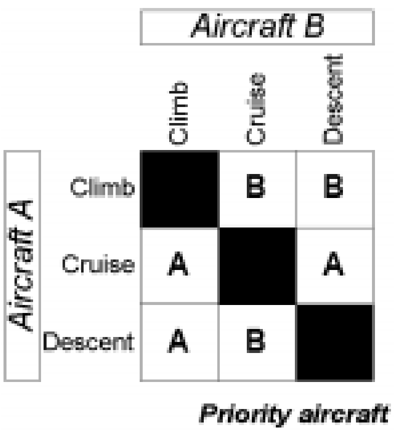


Fig. 3 Matrix of Phase-of-Flight Priority (PFP) rules

2.2.3 Rule 3. Extended VFR Overtaking Rules (EVOR)

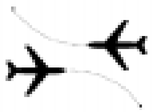
ICAO sets forth standard rules for overtaking in VFR conditions. These rules were designed for use in conditions in which electronic surveillance data are not available, and they have the advantage of being straightforward and reliable. The basic requirement of VFR states that any overtaking aircraft should do so on the starboard (right) side of other craft, so that the other craft remains to the port (left) side of ownship during the overtake. The rationale for this requirement stems from the enhanced field-of-view that this configuration affords the left seat pilot.

Clearly, VFR overtaking rules can be very inefficient and ambiguous under certain circumstances. For instance, VFR rules state that if a faster aircraft wishes to overtake a slower aircraft (on roughly the same heading), it must alter its heading so as to pass to the starboard side of the other craft even though it is already established to the port side of the slower aircraft. However, VFR do not address at what level of lateral separation this overtaking rule no longer applies.

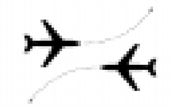
To correct some of the ambiguities and inefficiencies of VFR overtaking rules, the ATLAS project suggested a set of relative separation rules that were designed for autonomous self-separating flights, operating at the same altitude. These rules allow for different evasive manoeuvres, depending on the angle of closure between two aircraft. As shown in figure 6, this set of rules distinguish the following three lateral segments of airspace around an aircraft: Port Front; Starboard Front; and Rear.

Fig. 4 Lateral airspace segments, for Extended VFR Overtaking rules

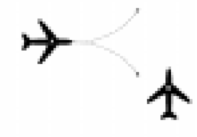
These airspace segments permit four EVORs to be specified, as depicted below.



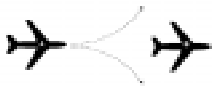
Rule 1: If both aircraft are both in the P region of the other, both turn right.



Rule 2: If both aircraft are in the S region of the other, both turn left. Figure 4b.



Rule 3: If aircraft A is in the P region of aircraft B's airspace, and aircraft B is in the S region of aircraft B, then A must turn in the direction that achieves separation with minimal deviation.



Rule 4: If aircraft A is in the R region of aircraft B, and aircraft B is in the S or P region of aircraft A (i.e., A is in-trail behind B), then aircraft A will turn in either direction to achieve separation with minimal deviation.

These four EVORs apply to situations in which vertical separation is not maintained. This might refer to two aircraft at cruise. It might also, though, refer to transitioning (ascending / descending) aircraft. For instance, EVOR Rule 2 would dictate that aircraft travelling in reciprocal headings, though in identical climbs, should achieve lateral separation. Second, in cases of identical heading (i.e., precisely head-on or in-trail), in which no preferred evasive path exists, VFR rules should still apply—that is, aircraft should turn right.

In some cases, it might not have been clear which rule to apply to a local conflict. For instance, if two aircraft are approaching at a slightly oblique angle and at the same flight level, it would not be clear whether to apply AFDOF (such aircraft should have already been separated by 1,000 feet) or EVOR (and allow the aircraft to pass to the starboard side of one another). In such cases, separation assurance is left to the discretion of the user (in this case, the pseudopilot and test controller), who is expected to consider the time available for establishing minimum safe separation. The rules 1, 2, and 3 will generally correspond, respectively, to more tactical timeframes. That is, if there is insufficient time to loss-of-separation to apply AFDOF, the aircraft would be expected to separate using EVOR.

It is believed that these three broad Extended Flight Rules (EFRs)—AFDOF, PFP, and EVOR--are sufficient to achieve self separation in localised encounters for most potential scenarios. AFDOF and EVOR together should apply to all possible cruise encounters. PFP rules would apply in most mixed-phase encounters (e.g., when one aircraft is ascending, and the other is at cruise). Certain same-phase encounters (e.g., both ascending through identical flight levels, though on reciprocal headings), cannot be addressed by the current EVOR. These were not examined in the current experiment.

2.3 The ATC Task

The experiment was based on a simulation of the Maastricht-Brussels en route airspace, in which controllers normally handle traffic along several intersecting paths. A series of traffic samples was created, all based on the same master traffic scenario. The master traffic scenario was carefully created and checked for realism by a subject matter expert. Slight modifications to the master traffic scenario yielded four highly similar (though non-identical) traffic samples, each 75 minutes in length. Traffic density was varied within each session to provide realistically extreme levels of traffic load. Traffic samples were checked and pre-tested for realism and traffic load equivalence (in terms of flight entry rate).

Whereas aircraft in conventional traffic samples were scripted to manoeuvre along the air route and beacon system, FF traffic samples followed a direct routing structure, as specified by a set of 32 Trajectory Change Points (TCPs) around the perimeter of the sector. These TCPs limited the number of points through which an aircraft might enter/exit the sector. Although FF conditions provided no flightplan as such, the display of entry and exit TCPs was under the control of the ATCo. Under FF conditions, aircraft appeared to generally track direct routes between these entry and exit TCPs, and manoeuvre only as needed to self-separate. Thus the FF traffic scenario simulated two key elements of a mature FF environment: (1) direct routing, and (2) self-separation. Figures 5 and 6 depict the display differences between CF and FF airspace, as well as between low and high traffic densities.

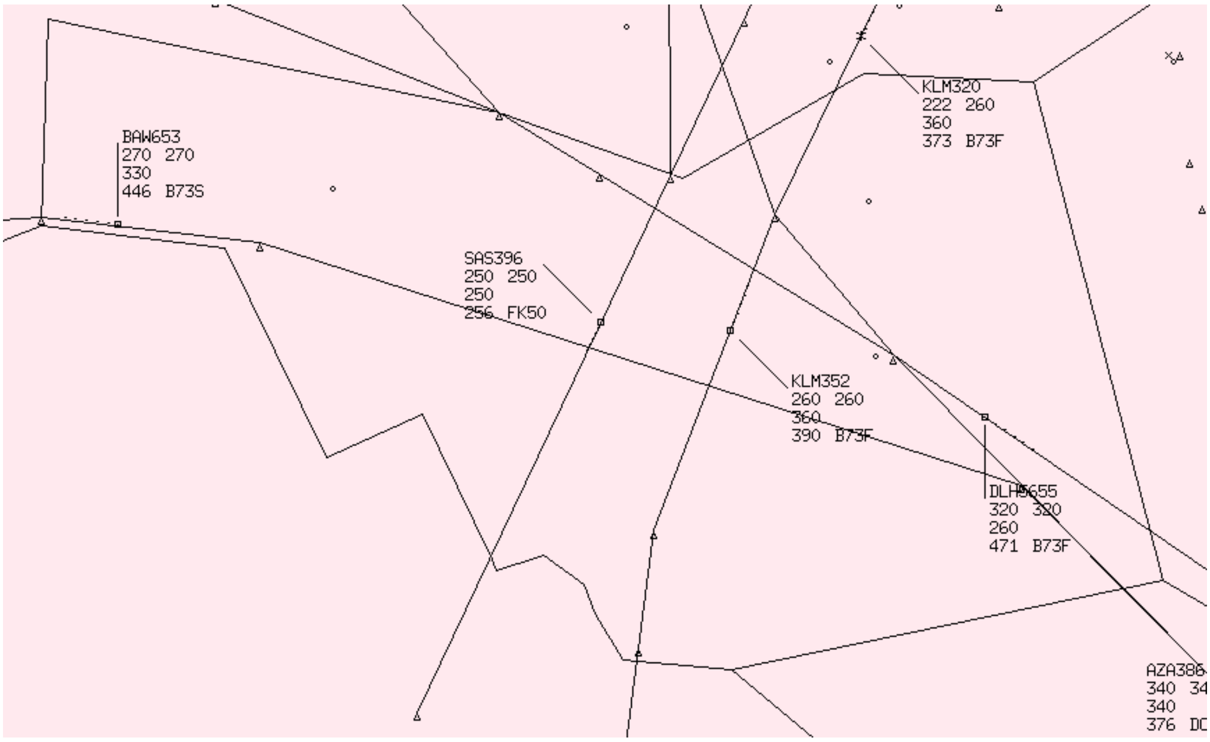


Fig. 5. Maastricht-Brussels en-route airspace (CF condition, low traffic)

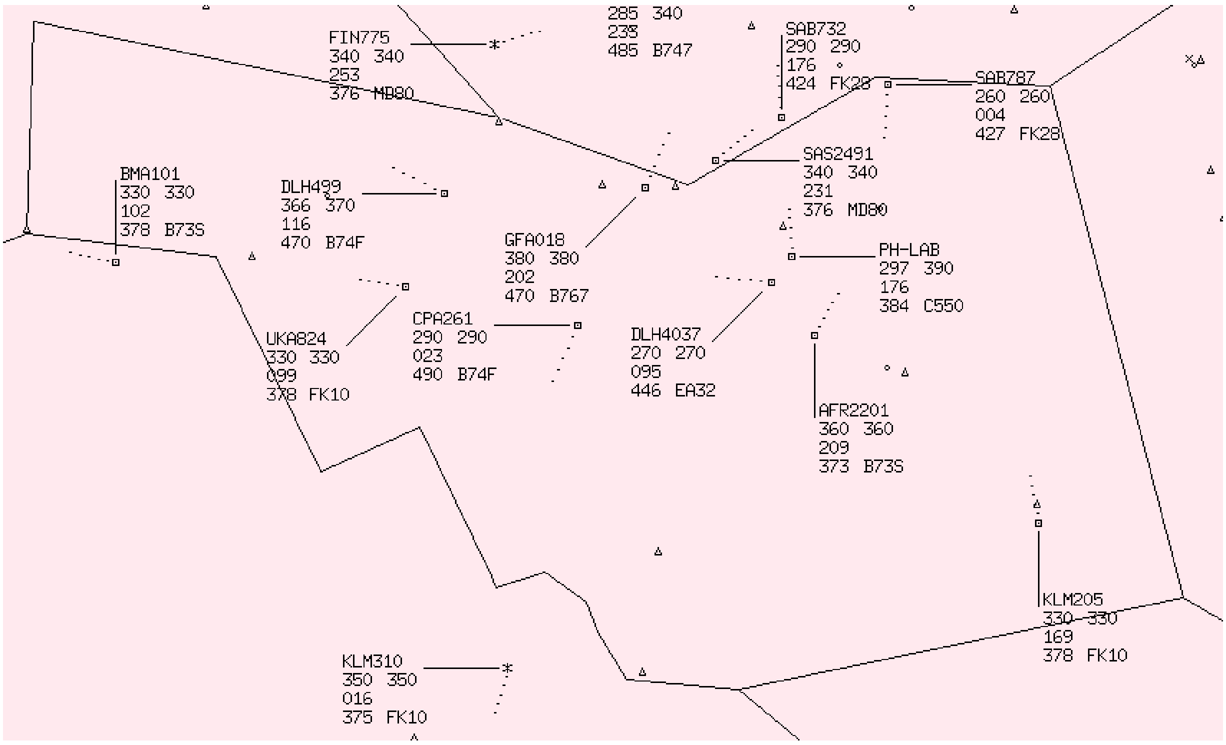


Fig. 6 Maastricht-Brussels en-route airspace (FF condition, high traffic)

2.3.1 Experimental Setting

This experiment was carried out using the NLR ATC Research Simulator (NARSIM), which provided for exact scripted control over the on-screen appearance and behaviour of aircraft. A photograph of the experimental setting is shown in figure 7. The ATC plan view display was presented on a Sony 2,000 x 2,000 pixel screen. Although interface modifications to the NARSIM system were minimised, free flight conditions did require the following display changes:

- Flight Data Block (FDB) presentation of both [1] ATCo-assigned, and
  [2] Aircraft-selected parameters (e.g., heading, speed).
- Suppressed display of routes and beacons under free flight sessions.

The format and appearance of the flight data block labels are shown in figure 8, for each of the three flight conditions. When ATCos assigned either a heading or altitude under FF (a non-nominal intervention) this was reflected in a third column within the data label. In figure 8, for instance, the ATCo has assigned the aircraft to a heading of 180, and has stopped its descent short (FL 300) of the aircraft's self-selected bottom of descent, FL 290.

Fig. 7 Experimental setting

Fig. 8 Flight data label format and appearance, by flight condition

Simulated aircraft were operated by a team of pseudopilots, either under the control of the ATCo test subject (under controlled flight conditions) or in accordance with session scripts (under free flight conditions). One pseudopilot played the role of the aircrew(s), while the other pseudopilot helped de-conflict traffic ("pseudo-controller"). Under free flight conditions, the appearance of co-ordinated airborne self-separation was simulated through the use of a FF conflict aid, an extended look-ahead probe that enabled the pseudopilot team to avoid or permit conflicts (as session scripts dictated). Figure 9 presents a schematic representation of the NARSIM functional architecture for this experiment including the communication link between parties, and the FF conflict detection aid.

Fig. 9 NARSIM functional architecture for this experiment

2.3.2 Procedure

Prior to their arrival at the NLR, each subject received a copy of the free flight training manual (NLR, 1997). This manual familiarised each controller with the interface, tools, and operational procedure for the trials. A total of three 75 minute training sessions, and three 75-minute test sessions, was carried out per subject. Traffic load was counterbalanced within session.

Under all flight conditions, ATCos were responsible for accepting and handing-off aircraft at sector boundaries. Under CF, controllers had to issue commands by Radio Telephony (RT). It was recognised that permitting controllers to exercise their preferred control strategies might deprive us of any data under FF conditions—that is, ATCos might be reluctant to actually permit FF. As a result, ATCos were instructed to intervene in the FF traffic pattern only in the case of an Short Term Conflict Alert (STCA) warning (several were scripted per FF session), when tactical avoidance was required.To permit a comparison between controlled-flight and free flight traffic samples of preferred resolution strategies, a verbal call-out procedure was used whereby subjects identified aircraft pairs according to a three-point separation criticality scale, as follows:

Level 1 Alert—

- I WOULD permit this situation under *controlled flight* conditions.
- Corrective action might be required in the future.

- I would continue to monitor this situation.

Level 2 Alert—

- I would NOT permit this situation under *controlled flight* conditions.
- Corrective action MIGHT be required in the future.

Level 3 Alert—

- Corrective action WILL PROBABLY be required.
- Loss of separation is imminent.

2.3.3 Traffic Samples

As shown on the following page, each traffic sample followed a Low - High - Low traffic pattern over 75 minutes, and was comprised of 20-minute low and high traffic periods averaging, respectively, roughly 10 and 17 aircraft under simultaneous control.

Fig. 10 Traffic load over time, for each 75-minute test session

2.4 Experimental Design

This experiment manipulated the following two factors in a repeated measures design: Flight Condition (3 levels), and Traffic load (2 levels). ATCos were provided familiarisation materials (regarding the task display and experimental protocol) in advance of their on-site participation. After a half-day of on-site familiarisation and training, each ATCo completed three 75-minute experimental sessions. Three levels of Flight Condition were defined (and their order randomised across ATCos), as follows:

- *Controlled Flight (CF)*— aircraft navigated according to standard route structure (unless instructed otherwise by controller), and manoeuvred only in response to controller-issued clearances.
- *FF with Intent Sharing (FFI)*— Route structure was neither displayed nor used, flightplans provided only sector entry/exit points, and aircraft shared their intentions with ATC before initiating any action.
- *FF without Intent Sharing* (FFN)— As above, although aircraft actions were not pre-announced to ATC.

Data from this study included a number of controller workload metrics, as well as system monitoring performance. Workload measures were of two types: Objective (pupil diameter and heart rate variability) and subjective (the Rating Scale for Mental Effort, or RSME (Zijlstra &

van Doorn, 1985)). Previous experience has shown these measures to be sensitive and reliable indicators of workload in simulated ATC tasks (Hilburn, Jorna and Parasuraman, 1995).

Pupil diameter data were collected with the Observer® eye tracking system, once per gaze fixation, with a theoretical resolution of .04mm. The RSME subjective workload scale is a simple paper-and-pencil instrument that requires subjects to indicate workload, on a continuous unidimensional scale. Controllers were instructed at several points throughout each session to rate their current workload using the RSME instrument. As appropriate, statistical analyses for all measures were carried out through univariate Analyses of Variance (ANOVAs).

Data analysis focused on the following research questions:

- What is the effect of FF traffic patterns on controller mental workload?
- Does the potential loss of aircraft intent information under FF impact controllers' response time to non-nominal events (e.g., STCA warnings)?
- Does this loss of intent information seem to degrade controllers' ability to anticipate critical events (e.g., losses of separation)?
- What are controllers' subjective impressions of a FF-like operational scenario?

3. Results

3.1 Controller workload

Again, controller workload was assessed using both objective (pupil diameter) and subjective (self-report) measures, and these will be discussed in turn.

3.1.1 Pupil diameter

Increases in mental workload are generally associated with small but measurable increases in pupil diameter. Indeed, a statistically significant difference ($p<.001$) was found between pupil diameter under low and high traffic—pupil diameter was seven percent (7%) higher under high traffic than under low traffic. The trend depicted in figure 11 shows that indicated workload was lower under the two FF conditions than under Controlled Flight. This was especially true under high traffic conditions.

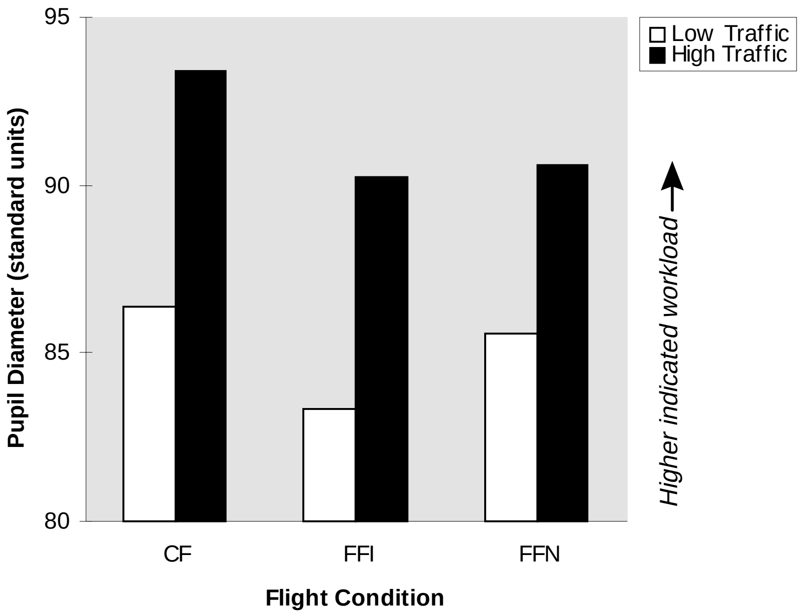


Fig. 11 Pupil diameter, by Flight Condition and Traffic Load

Note: CF = controlled flight, FFI = Free Flight with intend info, FFN = FF without intent info

3.1.2 RSME Subjective Mental Workload

Controllers reported significantly higher workload under high traffic conditions, ($p<.0001$). No main effect of control condition was found on RSME scores. A significant interaction was found between traffic level and control condition, ($p<.05$). This interaction is depicted in figure 12.

A post hoc Newman-Keuls test revealed that, under high traffic, controllers felt significantly more workload under controlled flight than they did under uninformed free flight (FFN), ($p<.05$).

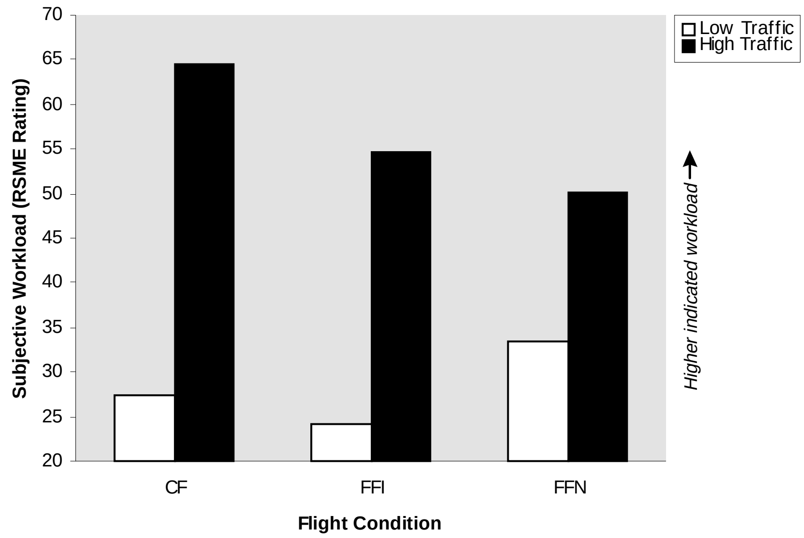


Fig. 12 Self-reported workload, by Flight Condition and Traffic Load

3.2 Monitoring Performance and Traffic Awareness

3.2.1 Response time to STCAs

Mean response times (from STCA onset to issuance of a corrective clearance) were calculated. Mean response times were lower for the CF than for either the FFI or FFN conditions, at 8.6, 10.0 and 9.9 seconds, respectively. FF traffic scenarios were scripted to provide a fixed number of situations (e.g., STCAs). This was obviously not the case under CF conditions, and as a result the number of STCAs differed dramatically between CF and FF conditions. Because of this difference (and the corresponding difference in standard deviations), statistical analysis of the response data (CF vs FF) is not appropriate. Comparing the two FF conditions, however, showed no significant difference in response times (10.0 secs. versus 9.9 secs.) between the informed (FFI) and uninformed (FFN) FF conditions—indeed, average response time to STCAs was slightly lower for the uninformed FF condition.

3.2.2 Conflict Prediction Accuracy under FF

It was realised at the outset that placing licensed, currently-active ATCos in a fundamentally new operational scenario (such as that posed by free flight) could introduce a host of complications. Among these is the likelihood that controllers would be unable to divorce themselves from their normal job behaviour. High fidelity simulations might further exacerbate this problem. This concern was addressed in several ways: First, through the choice of test subject population (out-of-sector military controllers); Second, through experimental protocol.

This forced the adoption of slightly different control procedures under controlled flight and free flight scenarios[1].

Under controlled flight, subjects were permitted to control traffic using standard RT procedures and clearances. Under free flight conditions, however, subjects were instructed to permit autonomous aircraft navigation unless a Short Term Conflict Alert (STCA) was displayed. Subjects were instructed that, should an STCA appear, they were to intervene in the control of aircraft, and issue whatever clearances they deemed necessary to ensure separation. To permit an assessment of the control strategies controllers would have used on the free flight samples, a verbal call-out procedure was used whereby controllers identified aircraft pairs according to the situation criticality scale, as discussed earlier. During free flight sessions, controllers identified each relevant situation by calling out the pair of associated aircraft callsigns. Controllers were permitted to identify both larger-scale situations (i.e., those involving three or more aircraft), as well as to update the criticality of evolving situations (e.g., one that has increased in severity from Level 2 to Level 3). Notice that Level 2 situations represent the threshold of intervention—Level 2 was the point at which the controller has declared that he/she would, under normal circumstances, intervene in the control of aircraft.

Recognising that controllers might have been less or more reluctant to report situations (under free flight) than they were to act on them (under controlled flight), the comparison of reported situations and observed interactions must be viewed with some caution. The comparison of reported situations is therefore more appropriate between the free flight conditions, to assess the impact of information sharing per se on the perceived need to tactically intervene.

Prediction accuracy was defined as the proportion of all STCAs for which a given controller had reported a potential conflict situation (according to the three-point severity scale), irrespective of the number of “false alarms” (i.e., situations in which a reported conflict did not result in an STCA)[2]. These data were available only under the FF conditions (since, under CF conditions, controllers were free to proactively control the traffic).

Controllers generally did not anticipate all STCA situations; Detection rates ranged from 0% to 100%. A statistically significant difference was found between prediction accuracy under low and high traffic, with averages of 88.0% and 33.2% under low and high traffic, respectively, ($p<.02$). Under FFI, controllers correctly predicted 64.9% of all STCA situations, whereas under FFN they correctly predicted only 53.3%. This difference failed to reach statistical

[1] Under all experimental scenarios, aircraft acceptance and hand-off were both achieved using standard RT calls to the aircraft.

[2] No pattern was discernible in controllers’ false alarms.

significance. A trend toward lower prediction accuracy for uninformed FF (FFN) appeared only under low traffic.

Fig. 13 STCA prediction accuracy, by flight condition and traffic load

3.2.3 Bias in Recognising Conflict Situations

Although controllers reported the same number of conflicts (i.e., an alert of Level 2 or higher) per session under informed and uninformed free flight (mean = 1.83), the conflict severity pattern is slightly different under the two. As shown below, controllers were more likely to call for immediate tactical intervention (Level 3 alert) in the case of uninformed free flight. This is noteworthy, given that no differences existed in either the number of scripted or actual conflicts (notice that the two might have differed if, for instance, in the process of intervening in conflicts, controllers had actually blundered into additional conflicts). This suggests that controllers might be biased against FFN and subjectively assess it as a more conflict-prone concept.

Fig. 14 Conflict prediction bias, by flight condition and level of alert

3.3 Intervention and Control Strategy Differences

All ATCo inputs and system interactions were logged during test sessions. Among the parameters logged was the occurrence of flightplan information requests made by the controller. The pattern of such information requests is shown in figure 15, by both Flight Condition and Traffic Level. Consistent with Endsley, Mogford and Stein (1997), who noted that FF might increase controllers' tendency to query aircraft, these data show that more flightplan information requests were made under FF than under CF conditions. The fact that number of queries <u>decreased</u> with traffic might simply be an indication of spare capacity-- ATCos might have tended to query only as time permitted. [3] Comparing the number of flightplan queries under the two FF conditions, it is interesting that <u>fewer</u> queries were made under the FFN condition, in which aircraft were not sharing their intentions with ATC.

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[3] Notice that, even under FF, ATCos remained responsible for hand-off and acceptance of aircraft, so the task was not one of entirely passive monitoring.

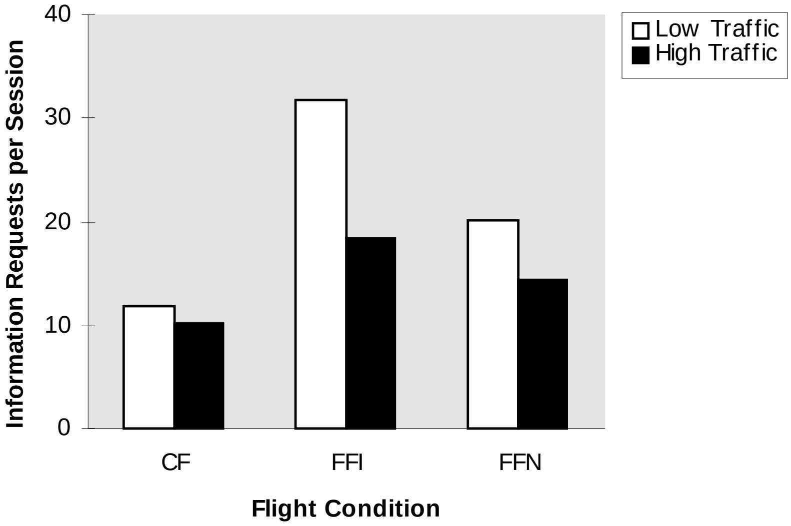

Fig. 15 Average number of flightplan information requests per session, by flight condition and traffic load

3.4 Survey Response Data

Because this study was intended as an exploratory analysis of free flight concepts, the experimental team sought to elicit as much subjective feedback from participants as possible. Post-test responses are summarised in the following graphics.

3.5 General Observations and Feedback

Because this study was intended as an exploratory investigation of FF concepts, the experimental team gathered a variety of data, including physiological and subjective workload measures, and objective behavioural measures. On the basis of these data, we can make the following observations:

- Controllers generally found FF surprisingly easy, and reported that workload was much lower than they had anticipated.
- Controllers also felt strongly that aircraft intentions should always be available to the controller.
- Error detection performance suggests that controllers were biased against free flight if intent information was withheld. Even though there were no more errors in FFN than in FFI, controllers reported more impending conflicts under FFN.
- Controllers generally felt that the Rules of the Road used for this study were clear, and facilitated detection of unusual situations.
- Most felt that conflict detection was more difficult under FF.
- Opinion was evenly split on whether STCA provided an adequate safety net function.
- Several controllers expressed concern that controllers under FF would be forced to over-rely on STCA, thereby depriving themselves of sufficient time and control options to resolve situations.
- Several controllers also volunteered that if aircraft had been free to communicate their intent to both ATC and to other aircraft, ATC could become safer and easier.
- Most controllers reported on shortcomings of the PVD interface. The need for label de-cluttering, ICAO destination designators (in flight data blocks) and velocity trend vectors were issues most mentioned.

4. Discussion

Trends in both objective and subjective workload measures suggest that FF can reduce workload, relative to CF conditions. Under low traffic density, the indicated workload reductions were greater for FFI than FFN—that is, shared intent information reduced controllers' indicated workload. Under high traffic, however, there was no pattern to suggest that shared intent information between air and ground reduced the controllers workload.

Given the large projected increases in air traffic, proponents of mature FF would probably be more interested in the high traffic density condition. Under high traffic, the indicated workload benefits of FF were more apparent. The objective and subjective measures were in essential agreement with one another, which in other studies of new ATM concepts has not always been the case (Hilburn, Jorna, and Parasuraman, 1995).

Monitoring data revealed that having manoeuvre intent information (FFI versus FFN) did not reduce response time to short term conflict alerts. Further, STCA prediction accuracy was nearly identical under high traffic conditions, regardless of whether intent information had been provided.

Consistent with the study of Endsley, Mogford and Stein (1997), controllers queried the system more under FF than under controlled flight conditions. Perhaps surprisingly, though, under FF controllers tended to query more when manoeuvre intent information was provided.

Summing up results, these data suggest the following:

- FF seems to reduce controller workload, especially under high traffic conditions.
- Overall, lack of manoeuvre intent information does not worsen controllers' ability to anticipate conflict situations.
- However, in the absence of manoeuvre intent information, controllers tended to overrate the criticality of emerging conflict situations.
- Intent information in general seems to benefit controllers' acceptance more than their workload.
- Controllers query the system more under FF, although are more likely to do so if manoeuvre intent information is provided.
- Controller acceptance of the FF concept might be fairly high.
- HMI display considerations will have to be further addressed in developing controller tools for FF.

The results of this experiment suggest that the potential human performance costs (e.g., mental workload increases) of FF might be smaller than those demonstrated by Endsley, Mogford and Stein (1997). In explaining this discrepancy, it might be instructive to consider two major differences between the two experimental protocols: First, the current study employed UK military ATCos, who (because of various operational differences from some of their civilian counterparts) might already be more favourably disposed to free flight concepts than some other controller populations (cf., Hilburn & Parasuraman, 1997). Indeed, the current sample of controllers reported that, on average, 86.25% of their on-the-job traffic request direct routings, and that 76.25% of these requests are granted. Second, the current study employed a fuller battery of workload measures. It is hoped that these measures together can provide a more complete picture of the influence that FF might have on the performance of the future ATCo.

The current experiment was intended as an exploratory analysis, to gain familiarity with some of the most salient aspects of possible FF operations (i.e., direct routing and self separation), and to gain an understanding of how these might impact human and system performance. As a result, interface changes were kept to a minimum. It is recognised that a mature FF environment would likely bring with it requirements for vastly redesigned ATC displays and control algorithms. This point is emerging from data on transient workload. Preliminary data analysis suggests that the workload benefits of manoeuvre intent sharing appear only <u>transiently</u>— namely, during the occasional non-nominal situation (such as during separation alerts). If this is so, it raises the possibility that advanced displays of aircraft manoeuvre intent might prove beneficial during such non-nominal situations. For instance, if ATCos were provided real-time displays that enabled them to verify that aircraft were co-ordinating joint evasive manoeuvres, would this reduce ATCos' transient workload? At least as importantly, would it allow them to better assess whether to intervene in the traffic pattern? These issues are to be explored further in an upcoming experiment.

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