Is limited delegation of separation assurance promising?

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Abstract

This paper presents an initial evaluation of the concept of limited delegation of separation assurance to the aircraft. The proposed concept relies on a key element – the "flexible use of delegation" – allowing each controller to select the most appropriate delegation level for each situation. Two classes of application are considered: crossing and passing in en-route airspace and sequencing in terminal areas. This initial evaluation has been set up to collect feedback from controllers and pilots, and to assess the operational feasibility and potential merit of the concept. The overall feeling can be summarised by "promising with a great potential". This concept would allow an increase of controller availability. In addition, the flexible use of delegation would provide flexibility to use the method under different conditions – traffic, airspace, practice level – and would also enable a gradual confidence building in the method. It has been observed however that the non respect of the applicability conditions of the method could result in an increase of workload and communication. The upcoming step will be a "quantitative" experiment with the objective of evaluating expected gains.

1 Introduction

The Evolutionary Air-ground Co-operative ATM Concepts (EACAC) study of the Freer Flight project is investigating the delegation by the controller to the pilot, of some tasks related to separation assurance. Starting from the analogy of visual clearances, EACAC is investigating the possibility of giving electronic clearances by making use of the new CNS/ATM technologies soon to be available [20], in conjunction with new operational procedures. EACAC targets near term applications – typically 2005 – taking place in current ATC organisations, while at the same time proposing long-term developments. This principle goes in line with the Operational Concept Document of the European Air Traffic Management System [12] and the ATM2000+ Strategy [11] proposed by EUROCONTROL which envisage within managed airspace, the possibility of transferring from the ground, part of the separation assurance to aircraft fitted with appropriate avionics.

Expected gains of this method are mainly an increased availability for the controller resulting from workload regulation and/or reduction. This increased availability is expected to provide safety improvements, and is also expected to be converted into increased capacity or increased efficiency depending on traffic conditions and airspace constraints. However, before setting up an experiment with the objective of evaluating these possible gains, an initial experiment was needed to get feedback from both controllers and pilots, and to assess the operational feasibility and potential interest of the concept. Due to the assumptions made – simple ATC environment, small number of participants – no quantitative measures could be made. The results of the evaluation are therefore qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses.

The paper is organised as follows: section 2 proposes a problem analysis through the notion of level of delegation. Section 3 outlines the concept of limited delegation and section 4 briefly presents a typical example. Section 5 describes the experiment and finally section 6 presents the results.

2 Problem analysis

A wide range of applications has been investigated so far in the domain of air/ground cooperative ATM, ranging from short term, e.g. oceanic in-trail climb, to longer term, e.g. autonomous aircraft under free-flight operations. A potential way to classify and characterise these applications is to introduce the notion of level of

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delegation, which seems also particularly suitable for analysing the whole concept of delegation.

Considering the general task of separation assurance from either human or system point of view, three sub tasks can be identified:

- Identification of problems, mainly detecting potential losses of separation (conflicts) between aircraft.
- Identification of a solution when a problem has been detected, typically identifying which aircraft has to manoeuvre and the type of manoeuvre to be executed, e.g. a left turn.
- Implementation of the solution, e.g. selection and activation of the appropriate heading changes, and monitoring of the implementation.

Following this description, three levels of delegation can be identified:

- Limited delegation. The controller is in charge of both problem and solution identifications. Only implementation of solutions and monitoring are delegated to the pilot.
- Extended delegation. The controller is in charge of the identification of problems, and delegate to the pilot the identification and implementation of the solution, and the monitoring.
- Full delegation. Pilots are responsible for all the tasks related to separation assurance: identification of problems and solutions, implementation and monitoring.

2.1 Full delegation

All the “autonomous aircraft”, “self separation” and “free-flight” applications fall in the context of full delegation [5][6][7][9][13][14][19]. This type of application is mainly intended to be applied in en-route airspace. Two types of organisation are targeted: either managed airspace with mixed equipage (i.e. equipped and non equipped aircraft) [6][19], or dedicated airspace with all aircraft equipped [7] such as the Free Flight Airspace proposed in [12].

In the context of managed airspace, the role of the controller would consist in providing separation for non-equipped aircraft while letting equipped aircraft self separating [6][19]. To reduce the possible interactions between equipped and non equipped aircraft, some “filters” can be added such as segregating aircraft by flight level or using protected airways for non-equipped aircraft [19]. These filters can also be considered as transition paths towards free-flight. In the context of dedicated airspace, all aircraft would have the responsibility for self separating. The role of the controller would thus dramatically change from traffic control to service regulatory, search and rescue, and possibly to flow management. In both organisations, the controller could also have the task to intervene on equipped aircraft to handle non nominal cases, such as when a conflict is not solved in due time (principle of “ATC by exception”). In such cases, the controller is moved from an “anticipative” behaviour to a “reactive” one, thus raising the question of a possible loss of situation awareness and possible increase of mental workload, as highlighted in [6][9]. Some experiments indicate that in a context of mixed equipages, the uncertainty about intent of equipped aircraft induces additional workload [6], and other experiments conducted with military controllers tried to compare situations with intent versus without intent [13]. It was also suggested that the operational background and the working practices of military controllers could be more appropriate for free flight scenario than their civilian counterparts [13].

On-board assistance tools for conflict detection and resolution are required to reduce pilot workload, along with intent information about other traffic, e.g. autopilot target values or Flight Management System (FMS) trajectories. A comparison of the benefits of using intent information has been carried out for conflict resolution in crossing situations [2]. A typical example of an intent based approach is [7], which relies on transmission of Trajectory Change Points (TCPs) extracted from the FMS. The system indicates conflict zones, and provides the pilot with different levels of assistance for conflict resolution: manual through a graphic editing, semi-automatic and automatic using a conflict solver. In addition, to ensure consistency between aircraft manoeuvres, Extended Flight Rules (EFR) have been set up, defining priorities between aircraft in conflict. Pilots must plan their trajectory for up to 6 minutes in advance according to their priority. Following this planning approach, [1] proposes an extension of the EFR towards complex multi-aircraft situations, using a “token allocation strategy” for setting priorities. On the opposite side, other studies [19] are based upon a reactive approach where all aircraft move at the same time following tactical advisories, i.e. no explicit coordination rule, no intent information, no planning.

2.2 Extended delegation

The extended delegation can occur in visual clearances. Although the encounter between two aircraft is identified and announced by the controller, the pilot can be in charge of altering his flight path to visually stay apart the designated traffic. A similar case happens in the approach phase, when the controller asks the pilot to visually stay apart from a lead aircraft. The “ASAS crossing procedure” proposed by CENA can be seen as another case of extended delegation, using a CDTI with in addition relative track information [3][4]. This application is intended to be used in an en-route and managed airspace. First the controller identifies a conflict, then he selects the manoeuvring aircraft and lets the pilot decide which solution to use. The delegation thus relies on controller initiative and uses a specific phraseology to communicate the instructions of delegation. It should be noted that the extended delegation requires less information and tools on board since conflict detection is performed by the controller. However, some intent information may still be required to identify the appropriate solution, along with some assistance for the pilot.

2.3 Limited delegation

The visual crossing report clearance is a typical case of limited delegation: the encounter between two aircraft is identified and announced by the controller. The pilot is in charge of reporting when he estimates visually that the crossing is completed and possibly of resuming his flight plan. A list of other possible applications of limited delegation has been proposed through RTCA [20] for instance station keeping, in-trail climb and descent. Information required on traffic is initially limited to flight state (position and velocity), along with a CDTI indicating velocity and closure rate of a target aircraft. For station keeping, an initial task scheduling has been proposed [24].

2.4 Discussion

Beyond the applications presented, the main issue arising in the context of the delegation in managed airspace is linked to the direct and side effects of the delegation that must be anticipated and mentally integrated by the controller. Indeed, the delegation is:

– Temporally limited, and the controller has to recover full management of separation assurance. (Specific to extended and limited delegation.)

and/or

– Spatially delimited, and the impact of trajectory modifications on non delegated or non equipped aircraft must be avoided. (Valid for all levels of delegation, full delegation in managed airspace included.)

However, the level of delegation may have a strong impact on (1) the predictability of pilot's possible future actions and trajectories, and (2) on the availability and situation awareness of the controller. Indeed, on one hand, a very limited delegation would maintain a high level of predictability of aircraft behaviours and trajectories from controller's point of view, with a counter part of limited gain in controller workload. On the other hand, a more extended delegation leaves more autonomy for the pilot to manage the solution, with a risk of a possible reduction of predictability for the controller. This should be considered carefully since at some extend, a "significant" loss (e.g. inability to anticipate any future actions and trajectories) would probably dramatically decrease the availability and the situation awareness of the controller ("mental picture" spoiled). As a side effect, the availability of the airspace occupancy would also decrease, and no gain in capacity, efficiency or safety could be expected. The potential risks and consequences of loss of mental picture are confirmed in [6]. Therefore, the level of delegation used appears to be a critical factor. Since the appropriate level of delegation strongly depend on traffic conditions, airspace constraints, and on the practice level of each controller, identifying and setting it in advance to its optimal level is thus not an option. The notion of "trade-off in human factor solutions" as introduced for ATC in general in [17] but is also valid for the delegation of separation assurance to aircraft. Hence, the selection of the delegation level should lead to reach such a trade-off.

In the EACAC concept, sub-levels of delegation are proposed, starting from "no delegation" to "limited delegation". Our underlying assumption is: depending on traffic conditions, airspace constraints, and controller's confidence in the delegation, an "optimal" level of delegation should be found by the controller, providing the best efficiency, while remaining acceptable for the pilot.

3 Outline of the concept

Two major constraints are driving the EACAC study. The first one relates to human acceptability, and can be expressed by the need to respect roles and working methods of controllers and pilots, to enable incremental practice and progressive confidence. Beyond, the underlying issue is to overcome the acceptance dilemma: no human-centred system can be used without confidence, but no confidence can be obtained without practising the system in real operations. The second constraint relates to technology and can be expressed by the need to rely on minimum assumptions for CNS facilities and equipment modification. In addition, to enable transition phases compatibility with stepwise fleet equipment should be guaranteed.

To meet these constraints, EACAC relies on a pragmatic and straightforward initial concept. Firstly, as for visual clearances, the concept is applicable for problems involving two aircraft: one aircraft (subject aircraft) receives the delegation with respect to the other aircraft (target aircraft). Secondly, the concept relies on the two following key points:

– **Limited delegation**: The task delegated to the pilot is limited to the monitoring and implementation of solutions. Thus, situation analysis, identification of problems (e.g. conflict detection), definition of solutions, and decision of delegation remain within role and responsibility of the controller. (However, the delegation requires pilot's agreement.)

– **Flexible use of delegation**: The level of task delegated to the pilot can range from monitoring up to implementation of a solution, and the controller has the ability and responsibility to select for each problem the appropriate level of delegation.

3.1 Working methods implications

In a context of limited delegation, the controller keeps the initiative and the overall authority on the situation management. Core roles and working methods of controllers and pilots remain unmodified: no dramatic change should be required, even if a new task – similar to visual clearance – is introduced for the pilot. Stepwise acceptance by controllers and pilots of the new delegation possibilities should be facilitated by the concept of flexible use of delegation. Indeed, the levels of delegation correspond to incremental steps of practice, yielding to gradual confidence building. The flexible use of delegation also allows for each individual controller to select the most appropriate level of delegation, depending on traffic conditions, airspace constraints, and his confidence and practice levels. This concept also introduces the first steps towards extended levels of delegation ("up to the pilot to identify an appropriate solution"), and ultimately towards full delegation ("autonomous aircraft").

3.2 Technology considerations

No significant modification of the controller working position is initially required. However, indication of aircraft equipage on progress strips or preferably on controller radar displays is essential for widespread usage of delegation of separation assurance. In terms of surveillance information available on-board the subject aircraft, position and velocity of the target aircraft transmitted through ADS-B or TIS-B are sufficient. Trajectory intent information (such as Trajectory Change Points) is not required since identification of problems and solutions is performed by the controller, but it can be used to increase the domain of applicability. In addition, surveillance information on surrounding traffic is not required. For the on-board assistance scheme, a minimum set of cockpit display enhancements are required to support delegation [23]. Connection to the FMS or to the autopilot is not required.

3.3 Applications

EACAC aims at covering two major classes of application: crossing and overtaking typically in en-route airspace, and sequencing operations typically in TMA (Terminal Manoeuvring Area). For each of these applications, three levels of delegation have been identified: basic, intermediate, and advanced. For the basic level, the delegation is extremely limited, hence enabling early practice. Beyond, the higher the delegation level, the higher the expected gain. However, a higher level imposes more restrictive conditions of applicability.

3.3.1 Crossing and overtaking

For crossing and overtaking applications, the three following levels of delegation have been identified:

Basic: identification of the "clear of target". The controller ensures the separation by issuing the appropriate initial clearance. The pilot has to identify and report the "clear of target" event. After the pilot's report, the controller is expected to authorise resume climb or normal navigation.

The pilot is assisting the controller by providing a timely reminder, with the aim of reducing controller's monitoring task by reporting the clear of target. No condition of applicability is required.

Intermediate: resume climb or normal navigation. Again, the controller ensures the separation by issuing the appropriate initial clearance. The pilot has to:

1. Identify and report the "clear of target" event, and then
2. Resume climb or normal navigation.

The controller is relieved of the "clear of target" monitoring and the resume clearance delivery tasks. In addition, the trajectories flown by the aircraft should be more efficient: shorter level-off or smaller deviations. In this case, separation assurance is partially delegated to the cockpit: typically, a too early or too "intensive" resumption could induce a conflict (typical problem for low converging encounters).

The conditions of applicability mainly reside in the capability of the delegated aircraft to predict the trajectory of the target aircraft during the "resume" period. Typically, if the target aircraft trajectory has a waypoint during the period considered, either this waypoint is transmitted and received by the delegated aircraft, or – if possible – the target aircraft is locked on its heading. Otherwise only the lower level of delegation can be used.

Advanced: implementation of manoeuvre. The controller identifies the conflict and selects the type of manoeuvre to provide separation. The pilot has to:

1. Work out the appropriate value for the specified manoeuvre, e.g. heading, and implement it;
2. Identify and report the "clear of target" event, then
3. Resume climb or normal navigation. The delegation ends at the "clear of target" report.

The controller is relieved of the implementation task, including adjustment of the solution manoeuvre, the continuous monitoring of the situation, and the resume clearance delivery. Again, trajectories should be even more efficient while the controller workload is significantly reduced.

As in the previous level, the conditions of applicability reside in the capability to predict the target aircraft trajectory during the delegation period. In addition, since the delegated aircraft is allowed to modify its trajectory, e.g. by heading adjustment, no interference with surrounding traffic is possible during the period considered.

3.3.2 Sequencing

For sequencing applications, the three following levels of delegation have been identified:

Basic: identification of separation. The aircraft are flying along the same trajectory, the trailing aircraft is faster than the lead one. The pilot has to report when reaching a specified separation distance.

The pilot is assisting the controller by providing a timely reminder, with the aim of reducing controller's monitoring work by reporting the establishment of the sequence.

The condition of applicability mainly relies on low closing speed and low to medium radiotelephony pressure.

Intermediate: station keeping. The aircraft are flying along the same trajectory, the trailing aircraft has to adjust its speed to maintain a given separation distance with respect to the lead aircraft.

The controller is relieved of separation monitoring and speed adjustment clearance delivery tasks.

The condition of applicability relies on same trajectories, and low closing speed. In case of building a sequence with multiple delegations, some conditions to ensure stability should be applied. This is being investigated.

Advanced: sequence establishment and traffic merging. Aircraft are flying along same or converging trajectories. The trailing aircraft has to adjust heading to provide the separation, and adjust speed to maintain the separation when the sequence is established.

The controller is relieved of the succession of monitoring, as well as heading and speed adjustment clearance delivery tasks.

For the converging phase, the conditions of applicability are similar to those applicable for crossing applications: capability to predict target aircraft trajectory and no interfering traffic. For the station keeping phase, the same conditions should be applied.

4 An example scenario

For illustration purposes, a typical scenario of vertical crossing is presented. The surveillance information of the target aircraft (position and velocity) either is transmitted by the target itself, e.g. via ADS-B, or is up-linked by a ground station, e.g. via TIS-B. The delegated aircraft has the capability to receive this surveillance information and is equipped with an enhanced CDTI (Cockpit Display of Traffic Information) helping to maintain separation.

Let us consider the following situation: the AZA321 is stable at FL250 and the BAW654 at FL390 requesting descent, but crossing AZA's trajectory.

Once the problem is identified, the controller decides to propose a delegation to the BAW aircraft. Below, the example of dialogue (read-backs of the pilot are omitted).

– Controller: "BAW654, select target 1234, position target"

The SSR code is used to designate the target aircraft (1234 is AZA's SSR code) instead of the callsign which is not permitted (risk of confusion). The BAW pilot enters the AZA's SSR code on the CDU (Control Display Unit) for display on the CDTI.

– BAW Pilot: "Target 1234 identified, 10 o'clock, 40Nm, 100FL below, BAW654"

The controller has the ability to select the appropriate level of delegation. If he selects the basic level, the instruction would be:

– Controller: "BAW654, descend FL260, report clear of target"

For the intermediate level:

– Controller: "BAW654, descend FL260 until clear of target, then resume descent FL210"

For the advanced level:

– Controller: "BAW654, pass above target, then descend FL210"

If the pilot accepts the delegation, he sets the CDTI to a Vertical Separation Assurance mode [23]. His task is then to adapt – as appropriate – the rate of descent to achieve the required separation, thus optimising any changes in profile.

When the clear of target is reached, for the basic level, the pilot's report would be:

– BAW Pilot: "BAW654, clear of target, request further descent"

For intermediate and advanced level, the report that ends the delegation, would be:

– BAW Pilot: “BAW654, clear of target, descending FL210”

5 The initial evaluation

The main objective of the initial evaluation was to get feedback on the concept from both controllers and pilots. At this stage and due to the assumptions made – simple ATC environment, small number of participants and limited occurrences of potential delegations – no quantitative measures could be made. The results are therefore qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses. (For more information, see [22].)

This “qualitative” evaluation is a first step before a “quantitative” evaluation, whose objective would be to evaluate possible gain in capacity, with different rates and levels of fleet equipment to assess transition feasibility.

5.1 Evaluation methodology

The following points, which are thought to constitute the major issues to be assessed, have been identified: operational feasibility and acceptability, potential interest and benefits, phraseology, tools and assistance needed.

The evaluation of these issues was made through questionnaires and debriefings. Two types of questionnaire were employed:

– On-line questionnaires that aimed at capturing the feeling of each on-going delegation.

– Off-line questionnaires which were intended to get a general feedback on the concept. One off-line questionnaire was given at the end of each session: en-route and ETMA.

5.2 Experiment conditions

The main constraint driving the definition of the evaluation was to minimise software development, and beyond, to minimise risks. For that purpose, the principle was to test the delegation procedures on the two cockpit simulators of the EUROCONTROL Experimental Centre, in a simplified ATC environment. More precisely, the experiment had the following characteristics:

– A representative real-time platform (developed for the Sweden Denmark ’98 simulation) was re-used and adapted.

– The two cockpit simulators were ASAS (Airborne Separation Assurance System) equipped. In this context, this means that surrounding traffic was available on-board through a CDTI, along with some additional indications to help the pilot, e.g. predicted distance at closest point of approach. However, this CDTI was in a basic version: all the assistance schemes envisaged [23] were not available. (The cockpit aspects will be evaluated separately.)

– The background traffic managed by pseudo pilot positions was not equipped. (It was decided to wait until the delegation procedures are assessed, before developing the delegation capabilities for the pseudo pilot positions.)

– Two sectors were available: one en-route and one “extended” TMA (ETMA), but only one sector was simulated at a time.

– Two controllers, executive and planning, were required and swapped roles during the experimentation.

– Two experiments were planned for a duration of one week for each (including presentations, training, simulation, and debriefings). The duration of the simulation was 2.5 days.

– The duration of each exercise was around 1h15. Each exercise generally contained eight problems presumed to be delegable, each involving one cockpit simulator and one aircraft from the background traffic. The exercises also contained “standard” problems in the background traffic, but not interfering with the delegated problems. (The traffic was adapted in order to provide such problems.)

– In the en-route sector, mainly vertical and lateral crossing with a few overtaking, were proposed for delegation. In the ETMA sector, sequencing applications were proposed, including both station keeping and traffic merging.

– A total of nine exercises were planned per week: six for en-route, and three for ETMA. Two French controllers attended the first session, two British and a Spanish attended the second.

– Due to the simplification of the cockpit side, only two airline pilots were involved: one participated to the en-route and ETMA exercises of the first session, and the other to ETMA exercises of the second. A professional pilot and a student pilot were flying the cockpit simulators the rest of the time.

6 Qualitative results

The following results treat on-line and off-line questionnaires separately. Firstly two separate synthesis of on-line controllers questionnaires are presented; one for en-route and one for ETMA (for pilots responses, see [22]). These are supported by illustrative results. Secondly a global synthesis of both en-route and ETMA off-line (controllers and pilots) questionnaires is presented.

6.1 Controller en-route on-line results

There were eighty potential delegations among all the scenarios but 16% of problems potentially delegable were not delegated mainly due to previous instructions that modified the scenario. Therefore, the following results are based on sixty-seven delegations.

Due to the characteristics of the simulation, no indications related to the task of identification of delegable problems (e.g. feasibility, resulting workload) could be obtained. Indeed, the ASAS equipped aircraft were indicated on the radar display, and thus were immediately identified as an aircraft potentially delegable.

Controllers mentioned that they never had difficulties to decide of which solution to adopt, and did not need more anticipation than today. Nevertheless, due to the pre-identification of delegated problems, this last point has to be considered carefully. In addition, they also stressed that "the sooner identified and delegated, the sooner available for other problems".

Figure 1 shows the percentage of the levels of delegation used.

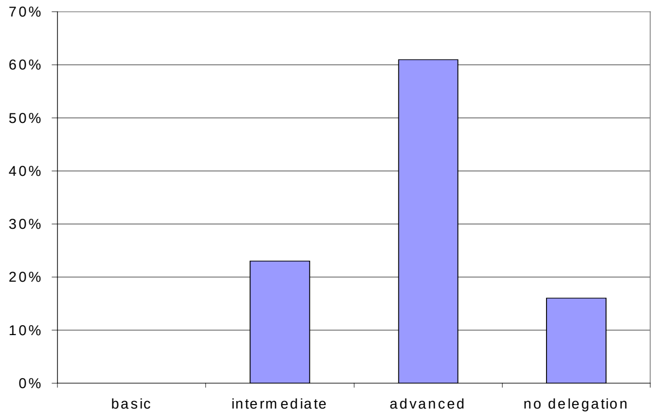

Figure 1: Levels of delegation used.

The advanced level was used for simple situations, i.e. no interfering aircraft, a stable trajectory of the target aircraft, and enough time to delegate. Otherwise the intermediate level was used. This level was also used at the beginning to acquire confidence. In addition, the intermediate level was preferred for vertical crossing, instead of the advanced level, which means clearing one aircraft through the level of another. The basic level was never used, possibly because the advanced (or intermediate) level was well adapted to the proposed problems.

Figure 2 presented feelings about the compatibility of the delegation with current methods, and Figure 3 the feelings about the delegation usefulness.

In some situations where the delegation to the cockpit simulators was not adapted, the controllers felt nevertheless obliged to delegate, which led them to adopt solutions different from today. Typically, in a lateral crossing with the cockpit simulator naturally passing ahead, the delegation results in a passing behind solution. Therefore, this could explain the 14% of "no compatibility".

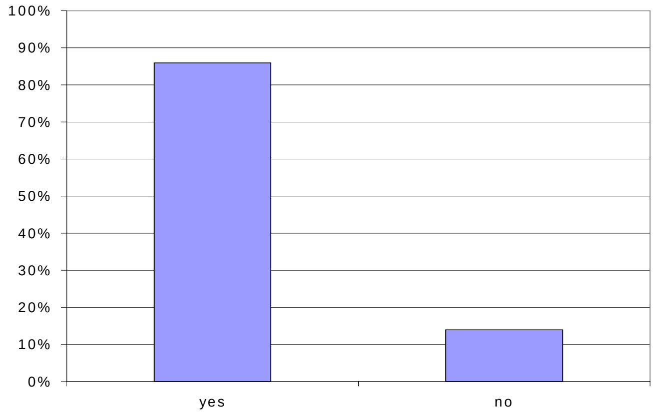

Figure 2: Delegation compatibility with current methods.

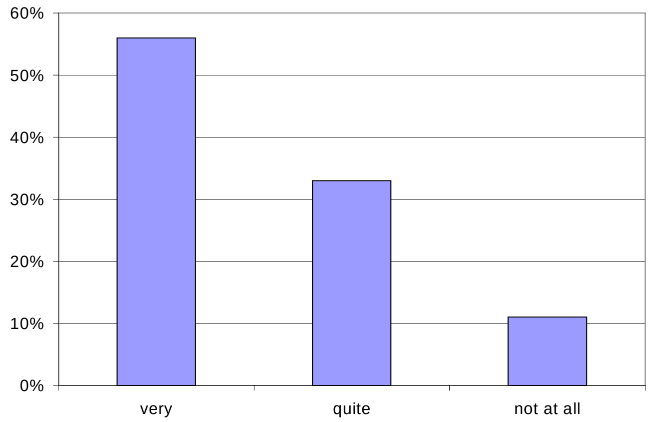

Figure 3: Usefulness of the delegation.

The controllers found the delegation useful since it allows (in a decreasing importance order): early resolutions, less monitoring, less communications, flight optimisations, and remove the need to find accurate manoeuvres. The "not at all" score is in the same order of magnitude of the "no compatibility" score (Figure 2) and may result from same reasons (conditions for delegation not respected).

The estimation by the controllers of compared workload (with delegation vs. current method) is presented in Figure 4. It appears a possible reduction of the workload using delegation. The controllers mentioned that the biggest contributions to this workload – even if presumed lower – were (in a decreasing order): the communication of the delegation instructions, the identification of the delegation level, the anticipation, and the monitoring. Similarly to previous results, the "higher" responses can be explained by conditions of delegation not respected.

The monitoring attached to delegations is thought to decrease, except when the pilot does not act as expected or objects, or an additional traffic suddenly appears, or an STCA (Short Term Conflict Alert) alarm is triggered. (All these situations occurred during the simulations.)

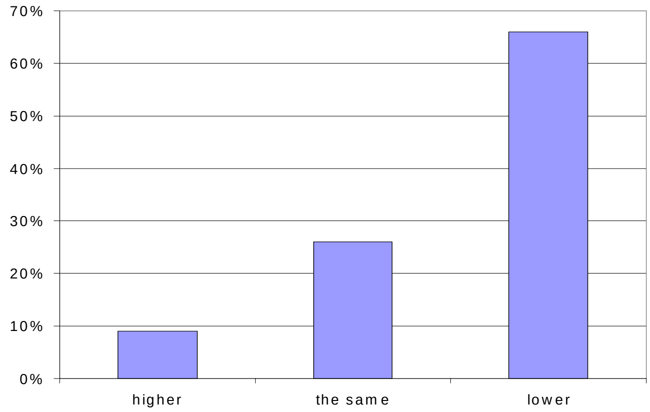

Figure 4: Comparison of workload between delegation and current methods.

6.2 Controller ETMA on-line results

There were forty-eight potential delegations among all the scenarios but 6% of problems potentially delegable were not delegated (same reasons as for en-route). Therefore, the following results are based on forty-five delegations.

As for en-route, no indications related to the task of identification of delegable problems could be obtained (due to the characteristics of the simulation). Again, the controllers mentioned they had no difficulties to decide which solution to adopt, and no need for more anticipation than today. (This should be considered with caution, due to the pre-identification of delegated problems.)

Figure 5 shows the percentage of the levels of delegation used.

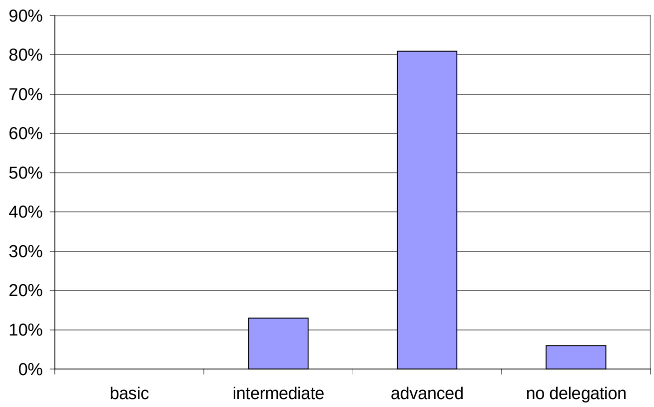

Figure 5: Levels of delegation used.

The advanced level was used very frequently. Nevertheless, for merging or station keeping situations where the aircraft are not separated, the controllers preferred to give a first heading to provide the initial spacing, and then delegate the “resume and follow”. This procedure was classed as an advanced level by the controllers. As for en-route, the basic level was never used, possibly because proposed problems were well adapted to advanced or intermediate levels.

As stressed in the outline of the concept, conditions of applicability have been identified and must be respected to ensure a safe and efficient delegation. Typically, for sequencing applications, the main condition relies on a low closing speed between target and subject aircraft. However, the respect of conditions of applicability was not clearly explained and stressed during the training of the first session. This led to many situations (about 50%) where the subject aircraft received a delegation to maintain a given distance, while the target aircraft was already descending with a difference of altitude between 6,000ft and 10,000ft. The difference between ground speeds was such that the subject aircraft could not maintain the distance by adjusting its speed. In addition, it could no longer respect the descent profile. Finally, a heading change was necessary to recover a normal situation. As a consequence, the monitoring increased and a back-up intervention of the controller was required, which was typically a counter-example of application. This point clearly appeared in the off-line questionnaires (see next section), and was largely mentioned during debriefing. If not used correctly, this method could worsen situations, increase workload and induce stress. During presentation and training for the second session, a special focus was given to the respect of conditions of applicability, leading to normal and expected executions of the delegations during exercises.

The abnormal and unexpected executions of delegation during the first session impacted on the reaction of the controllers, typically concerning usefulness. For this reason, the results of both sessions are presented as well as those of the second session.

The following figures present the delegation compatibility with current methods (Figure 6) and the usefulness of the delegation (Figure 7). Figure 6 shows that the delegation was found generally compatible with current methods for a high majority, even with the results of the first session. Figure 7 indicates balanced opinions, which result from the difference between the respect of conditions of applicability. For the cases where conditions of applicability were respected, the reasons for usefulness mentioned by the controllers were (in a decreasing order): less communication (no need to control the speed), less monitoring, and better flow streaming. The estimation by the controllers of the compared workload (delegation vs. current method) is presented in Figure 8.

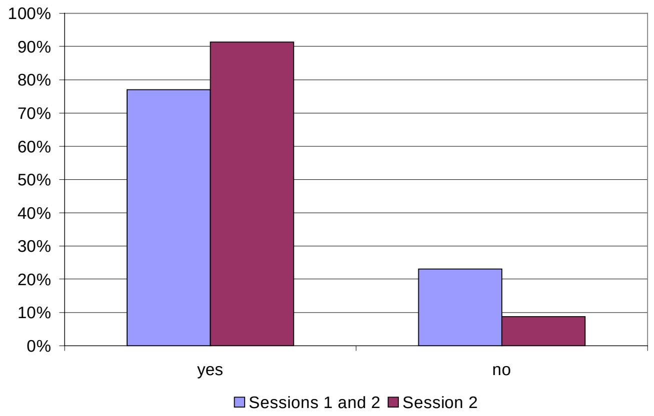

Figure 6: Delegation compatibility with current methods.

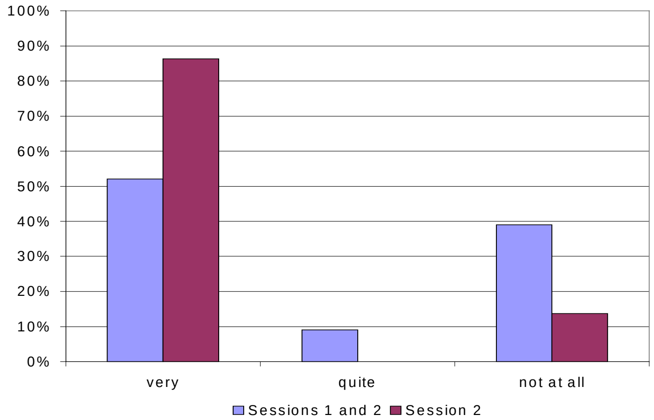

Figure 7: Usefulness of the delegation.

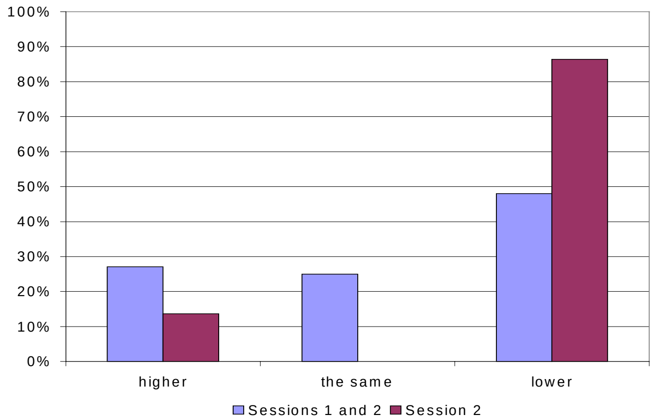

Figure 8: Comparison of workload between delegation and current methods.

Again, results of Figure 8 indicate balanced opinions, resulting from the difference between the respect of conditions of applicability. For both sessions, the workload was considered to be lower for almost 50% of the delegations, while this increased up to 80% for the second session. For the cases where conditions of applicability were respected, the biggest contributions to the workload – even if presumed lower – were (in a decreasing order): the communication of the delegation instructions, the identification of the delegation level, and the monitoring. The monitoring is thought to decrease, and less communications than today are needed. The controllers also mentioned that although more communication was required to initiate the delegation, it decreased after, thus leading to an overall decrease of the communications. As a consequence, they felt more available for the rest of the traffic.

6.3 Off-line comments

The concept was generally understood. Deciding the appropriate level of delegation is sometimes not so easy. For each situation, a compromise between what is good for the pilot (optimisation) and benefits for the controller according to a given situation has to be found. Despite the simulation limitations, the experiment allowed the controllers to have a clear idea of the concept. The unfamiliarity with the HMI and with the airspace did not seem to have been a handicap.

Overall, the method is considered “totally feasible” from a technical point of view, since the procedures are the same as today. Assuming that adequate airborne tools are provided, this concept enables separation of the decision making from the implementation of solutions, with better results. The difficult aspects to implement mentioned were the identification of the level of delegation, the communication of the delegation instructions, and sometimes the new monitoring task of the delegated aircraft considered as a “passive” monitoring.

The method is thought generally “compatible” with current working methods: procedures are the same as today and can fit anywhere within the ATC system. For the vertical crossing delegation, clearing an aircraft through target aircraft level (i.e. advanced level of delegation) might be found difficult to accept. Indeed, it may not be possible for the controller to identify that the pilot is reacting properly (i.e. detecting the modification of the vertical profile), thus it possibly induces a more stressful “passive” monitoring. In such situations, the intermediate level was preferred (see Figure 1).

The method is considered “absolutely feasible” from a human point of view: The confident controllers feel that used in appropriate circumstances the resulting monitoring would decrease and would allow the controller to have more time to concentrate on the rest of the traffic, without changing current working methods. The less confident ones fear a higher monitoring task increasing their workload. All of them mention that the legal aspects must be clearly defined. The main difficulty mentioned is to identify the appropriate level of delegation for each situation, and beyond that to give high levels of delegation. Typically in en-route, handing over the responsibility of the separation to the pilot may be difficult, due to lack of confidence in the pilot and fear of losing control of the situation. For ETMA, to keep the situation safe and under control in merging and station keeping with aircraft not separated, the controllers prefer to initialise the sequence by giving a first heading, then delegate the “resume and follow”. The “passive” monitoring of the delegated aircraft may also be difficult to accept.

The frequency of use of the method under low workload is thought to be “globally often”. Indeed, the controllers feel they would have time to prepare and give delegations and to monitor the flight actions. For en-route they would use it mainly for flight optimisation, and for ETMA to have a better flow streaming. For the frequency of use under medium workload, no real trend appears. The answers vary from very “often” to “sometimes”, depending on the confidence each controller has in the method. Those who are confident would use it “often” or “very often” since it would reduce their workload and give them extra time to concentrate on the rest of the traffic. Typically, for ETMA the method would allow more efficient flow streaming and management. Those who are less confident fear to have inadequate time to prepare, give and monitor delegations, and not enough radio availability. As a consequence, they would use it only “sometimes”. Similarly, for the frequency of use under high workload: no real trend appears. There is a difference between the controllers depending on their confidence in the method. The confident controllers would use it “often” since it would enable heavy task load to be accommodated (i.e. workload regulation). The less confident feel that – at least for the advanced level – the situations will probably be too complex and they would not have enough time to prepare, communicate (frequency occupancy) and monitor the delegations. For all of them, the question of availability for “passive” monitoring (i.e. monitoring of the delegated aircraft) is an issue, which should be thoroughly investigated.

Concerning the conditions of applicability, no new specific conditions other than those presented have been identified. Those proposed have been generally approved. Some controllers feel the need to have more application-oriented conditions.

The method is found globally useful and effective: it may reduce controller workload, enabling him to undertake other tasks. It may also enable trajectory optimisation and better flow management. However, the method should be used with caution (respecting conditions of applicability) otherwise it could become rapidly a concern and a source of stress (typically, see on-line results for ETMA).

The controllers felt that enough confidence in the crew could be obtained, with a step by step practice, i.e. 1st and 2nd level to start with and only then go for 3rd level. They also mentioned that confidence will be more easily acquired with familiar companies (e.g. BAW for UK controllers). It is generally agreed that three levels of delegation would build gradual confidence in the method and would provide flexibility. A certain gain in safety could be expected. The expected gain in capacity varies according to the degree of confidence in the method. The average feeling is between “partially” and “maybe”. It was also mentioned that the more aircraft which are equipped, the more effective the method will be. Under a certain threshold either the method would not be used or usable, or the equipped flight would be penalised. Further, the concept is seen as an additional tool, promising and with a great potential. An important issue stressed is the need for a clear definition of the sharing of responsibility between pilot and controller. This would have to be solved before even thinking of implementing this method. Also, the training of both controllers and pilots is an important issue to guarantee a safe and efficient use of the method.

For the pilots, the tasks delegated are found interesting: a better flight management and trajectory optimisation could be obtained. The method also allows a better understanding of the air situation from the pilot point of view. However, the workload in the cockpit would increase, and may induce stress. The method is thought compatible with current working methods, but may be not compatible under abnormal situations (e.g. adverse weather, minor failure). The pilots made a correlation between levels of delegation and levels of responsibility, and they mentioned that different levels could allow to gradually adopt the method. However, although the change of responsibility for separation assurance is felt generally acceptable, it could make it harder to accept the method (at least the higher levels).

7 Conclusion

The study presented is investigating the delegation by the controller to the pilot, of some tasks related to separation assurance. At this stage of the study, it was necessary to get feedback from both controllers and pilots, in order to assess the operational feasibility and potential interest of the concept. For that purpose, an initial evaluation in a simplified ATC environment has been set up, providing qualitative indications gathered through questionnaires and debriefings. The overall feeling about the method is “promising with a great potential”: controller availability could be increased. In addition, the notion of “flexible use of delegation”, which enables the controller to select the appropriate task to be delegated to the pilot, would enable gradual growth of confidence in the method. This notion would also provide flexibility to use the method under different traffic conditions, airspace constraints, and controller’s practice level. It has been observed however that the non respect of the applicability conditions of the method could result in an increase of workload and communication.

The upcoming step will therefore be a "quantitative" experiment with the objective of evaluating expected gains in a more realistic environment. The characteristics of the experiment are set. The main differences rely on three key points: all aircraft ASAS equipped, two sectors simulated at a time to experiment the coordination procedures, and use of a high density airspace. Similarly to the previous experiment, two distinct organisations will be simulated: extended TMA for sequencing applications, and en-route for crossing and passing applications. A representative high density airspace will be used for these two organisations: four sectors from South-East of Paris (sectors UJ, UT/TU, AO, and AR) combined into two sectors. Two sessions are planned (Summer and Fall '00), one session including two weeks of simulation (one week for extended TMA and one for en-route).

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References

[1] J.-M. Alliot, N. Durand, G. Granger, "FACES: a free-flight autonomous and coordinated embarked solver", *USA/Europe ATM R&D Seminar*, Orlando, 1998.

[2] R. Barhydt, J. Hansman, "Experimental studies of the intent information on cockpit traffic display", Journal of Guidance Control and Dynamics v. 22 no4 p. 520-7, 1999.

[3] B. Bonnemaison, F. Casaux, T. Miquel, "Operational assessment of co-operative ASAS applications", *USA/Europe ATM R&D Seminar*, Orlando, 1998.

[4] F. Casaux, B. Hasquenoph, "Operational use of ASAS", *USA/Europe ATM R&D Seminar*, Saclay, France, 1997.

[5] P. Cashio, M.A. Mackintosh, A. McGann, S. Lozito, "A study of commercial flight crew self-separation", *IEEE/AIAA Digital Avionics Systems Conference*, 1997.

[6] K. Corker, K. Flemming, J. Lane, "Measuring controller reactions to free flight in a complex transition sector", *Journal of ATC*, October-December, 1999.

[7] V. Duong, E. Hoffman, "Conflict resolution advisory service in autonomous aircraft operations", *IEEE/AIAA Digital Avionics Systems Conference*, 1997.

[8] EMERALD (European Community funded project), "Research and technical development plan for ASAS concept development", WP5.5 report 3.0, March 1998.

[9] M.R. Endsley, "Situation awareness, automation and free-flight", *USA/Europe ATM R&D Seminar*, Saclay, France, 1997.

[10] M.R. Endsley, D.B. Kaber, "Level of automation effects on performance, situation awareness and workload in a dynamic control task", *Ergonomics*, 42(3), pp. 462-492, 1999

[11] EUROCONTROL, *ATM Strategy for 2000+*, Issue January 2000.

[12] EUROCONTROL, *EATMS Operational Concept Document*, Issue January 1999.

[13] B.G. Hilburn, M.W.P. Bakker, W.D. Pakela, R. Parasuraman, "The effect of free flight on air traffic controller mental workload, monitoring and system performance", *European Aerospace Conference on Free Flight*, 14(1-12), Amsterdam, 1997.

[14] W. Johnson, V. Battiste, S. Delzell, S. Holland, S. Belcher, K. Jordan, "Development and demonstration of a prototype free flight CDTI", *SAE/AIAA World Aviation Congress*, 1997.

[15] W. Johnson, V. Battiste, S. Holland, "A Cockpit Display Designed to Enable Limited Flight Deck Separation Responsibility", SAE/AIAA World Aviation Congress, San Francisco, October 1999.

[16] E.M. Morphew, C.D. Wickens, "Pilot performance and workload using traffic displays to support free flight", *Annual Meeting of the Human Factors & Ergonomics Society*, Santa Monica, CA, 1998.

[17] National Research Council, *Flight to the future – Human factors in air traffic control*, C.D. Wickens, A.S. Mavor, J.P. McGee eds, National Academy Press, Washington, D.C, 1997.

[18] A. Pritchett, "Simultaneous design of cockpit display of traffic information and air traffic management procedures", *SAE/AIAA World Aviation Congress*, 1998.

[19] R. Ruigrok, R. Van Gent, J. Hoekstra, "The transition towards free flight: a human factors evaluation of mixed equipage, integrated air-ground, free flight ATM scenarios", *SAE/AIAA World Aviation Congress*, San Francisco, 1999.

[20] RTCA SC-186, *Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)*, DO-242.

[21] RTCA, SC-186, *Guidance for Initial Implementation of Cockpit Display of Traffic Information*, DO-243, 1998.

[22] K. Zeghal, E. Hoffman, J.-P. Nicolaon, A. Cloerec, I. Grimaud, "Initial evaluation of limited delegation of separation assurance to the cockpit", *SAE/AIAA World Aviation Congress*, San Francisco, October 1999.

[23] K. Zeghal, E. Hoffman, "Design of cockpit displays for limited delegation of separation assurance", *IEEE/AIAA Digital Avionics System Conference*, St Louis, Missouri, October 1999.

[24] D. Zeitlin, J. Hammer, J. Cieplak, B. O. Olmos, "Achieving early CDTI capability with ADS-B", *USA/Europe ATM R&D Seminar*, Orlando, 1998.