Initial Evaluation of Limited Delegation of Separation Assurance to the Cockpit

Karim ZEGHAL, Eric HOFFMAN, Anne CLOEREC, Isabelle GRIMAUD, Jean-Pierre NICOLAON
EUROCONTROL Experimental Centre, BP 15, F-91222, Bretigny, France

ABSTRACT
This paper presents the initial evaluation of the EACAC study, which is investigating delegation by the controller to the pilot of some tasks related to separation assurance. The concept is applied in managed airspace for two classes of application: crossing and passing in en-route, and sequencing in Terminal Manoeuvring Area. The concept relies on two key points discussed in the paper: “limited delegation” and “flexible use of delegation”. The initial evaluation using a simplified ATC environment has been set up to get “feedback” from both controllers and pilots, and to assess the operational feasibility and potential interest of the concept. The overall feeling about the method is “promising” with a “great potential”, and could reduce workload. The notion of “flexible use of delegation” would enable the gradual growth of confidence and would also provide flexibility to use the method under different conditions (traffic, airspace, practice level). It has been highlighted and observed however that the conditions of applicability of the method must be respected, otherwise it could worsen the situations, resulting in an increase of workload and communication. The next step of the study will therefore be a “quantitative” experiment with the objective of evaluating expected gains of the method.

INTRODUCTION
The forecasts for growth in traffic density in Europe and in the United States over the next fifteen years suggest that improving ground systems alone might not be sufficient to achieve the required capacity at appropriate safety levels. To achieve that, it will be necessary to develop close air/ground cooperation. Transfer to aircraft of ATC problems is one of the possibilities for air/ground cooperation, which is now on offer.

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, 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 [9] and the ATM2000+ Strategy [8] 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 resulting from the application of this concept are mainly an increase in capacity through a reduction of controller workload, together with the improvement of safety and flight efficiency. 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: the following section outlines the concept of limited delegation. The next section presents some typical examples of application, and the final one presents the results of the evaluation.

1 For a discussion of related issues, please refer to [13].
PROBLEM ANALYSIS THROUGH LEVELS OF DELEGATION

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 promising way to classify and characterise these applications is to introduce the notion of *level of delegation*, which seems also particularly suitable for analysing the whole concept of delegation.

Considering the problem of separation assurance from either human or system point of view, three high level tasks can be identified:

- Identification of problems, typically detecting potential losses of separation (conflicts) between aircraft.
- Identification of a solution when a problem has been identified, typically finding the type of manoeuvre to solve a conflict, e.g. left turn.
- Implementation of the solution, e.g. selection and activation of the appropriate magnitude of heading changes, and monitoring of the implementation.

Following this high level description, three major levels of delegation can be identified, in an increasing order:

- **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.

All the “autonomous aircraft” and “free-flight” applications fall in the context of “full delegation” [e.g. 1, 6, 12]. In this context, intent information is normally required, provided by target values of the autopilot or by Trajectory Change Points (TCPs) from the Flight Management System (FMS). To contain the workload of the pilot, “advanced tools” on-board for conflict detection and resolution are also required.

Typically, FRER [6] relies on transmission of TCPs extracted from the FMS. FRER 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. From a theoretical point of view, FRER relies on a planning approach: 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. The NLR study [12] is based upon a reactive approach where all aircraft move at the same time following tactical advisories (no EFR, no planning). In all these “full delegation” applications, however, the role of the controller would dramatically change.

The “ASAS crossing procedure” proposed by CENA can be seen as a typical case of “extended delegation”, using a Cockpit Display of Traffic Information (CDTI) that indicates relative speed line [3, 4]. 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.

The visual 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 announcing when the crossing is completed, and possibly resume his flight plan. Other applications of “limited delegation” are those proposed through RTCA [17, 18]: station keeping, in-trail climb and descent. Information required on traffic is limited to flight state (position and velocity), along with a CDTI indicating velocity and closure rate of a target aircraft. For station keeping applications, an initial task scheduling has been proposed [18].

Beyond these applications, the main issue arising in the context of managed airspace, concerns 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 responsibility of separation assurance,
- spatially delimited, and the impact of trajectory modifications on surrounding traffic must be avoided.

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 extent, 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 or in safety could be expected.

Identifying and setting in advance the appropriate level of delegation seems unrealistic, since it would strongly depend on traffic conditions, airspace constraints, and also on controller's confidence in the method. For that purpose, different levels of delegation should be
available for the controller, allowing to tend to a “trade-off in human factor solutions” [16].

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.

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). In addition, depending on the task delegated, conditions of applicability in terms of complexity of problems have been identified. These must be respected. Secondly, the concept relies on the 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 transfer 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.

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 is 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”).

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 [14]. Connections to the FMS or to the autopilot are not required.

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.

CROSSING AND OVERTAKING

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

- **Basic**: identification of the “clear of traffic”. The controller ensures the separation by issuing the appropriate initial clearance. The pilot has to identify and report the “clear of traffic” event. After the pilot’s report, the controller is expected to authorise resume climb/descent or normal navigation.

No delegation of separation assurance takes place: 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 traffic. No condition of applicability is required.

**Intermediate: resume climb/descent 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 traffic” event, and then
2. Resume climb/descent or normal navigation.

The controller is relieved of the “clear of traffic” 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 a manoeuvre option to provide separation. The pilot has to:

1. Work out the target value for the appropriate manoeuvre, e.g. heading, and implement it;
2. Identify and report the “clear of traffic” event, then
3. Resume climb/descent or normal navigation. The delegation ends at the “clear of traffic” 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. In this case, assuming that the type of manoeuvre identified by the controller would be acceptable and would solve the problem, the primary responsibility for separation assurance is transferred to the pilot.

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.

**EXAMPLE SCENARIOS**

For illustration purposes, two typical scenarios are presented, along with the phraseology. 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.

**VERTICAL CROSSING**

Let us consider the case of vertical separation application between AZA321 stable at FL250 and 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 electronic traffic 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**: “Traffic 1234 identified, 10 o’clock, 40Nm, 100FL below”

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 traffic”

For the intermediate level:

- **Controller**: “BAW654, descend FL260 until clear of traffic, 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 Vertical Separation Assurance mode. 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 traffic is reached, for the basic level, the pilot’s report would be:

- **BAW Pilot**: “clear of traffic, request further descent”

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

- **BAW Pilot**: “clear of traffic, descending FL210”

**STATION KEEPING**

Below is an example of dialogue for a station keeping between AFR123 and DLH456, in the initial approach phase. Once the problem is identified, the controller decides to propose to the AFR pilot the task of maintaining his distance behind the DLH aircraft.

- **Controller**: “AFR123, for station keeping, select electronic traffic 4321, 10Nm ahead”

- **AFR Pilot**: “Traffic 4321 identified”

- **Controller**: “AFR123, adjust speed to maintain 5Nm behind target”

If the AFR pilot accepts, he sets the CDTI to Station-Keeping mode. The along track distance and the projected path of the other aircraft are then displayed, as well as the closing speed, enabling the pilot to adjust the aircraft speed as appropriate.

At the end of the downwind leg, the controller ends the delegation:

- **Controller**: “AFR123, end of delegation, contact approach 118.xx”

**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.

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.

**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.**

**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 [14] were not developed. (The cockpit aspects will be evaluated separately.)**
• The background traffic managed by pseudo pilot positions was not equipped. (The key point was 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 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.

QUALITATIVE RESULTS

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

CONTROLLER EN-ROUTE ON-LINE RESULTS

Delegation initialisation

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.

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. As shown in Figure 2, the controllers generally did not hesitated in deciding the level of delegation to give.

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. As shown in Figure 2, the controllers generally did not hesitated in deciding the level of delegation to give.
Figure 2: Hesitation for the level of delegation.

Figure 3 presented feelings about the compatibility of the delegation with current methods, and Figure 4 the feelings about the delegation usefulness.

Figure 3: Delegation compatibility with current methods.

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 may partly explain the 14% "no compatibility".

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.

Delegation procedure

The estimation by the controllers of the overall workload resulting from the delegation is presented in Figure 5, and the comparison with current methods is presented in Figure 6. Figure 5 indicates that for 72% of the delegations, the overall workload resulting from the delegation was considered to be low or very low, and Figure 6 indicates a possible reduction of the workload. 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.

Delegation monitoring

The previous figures relate to the overall workload of the delegation, including the monitoring tasks. The workload solely induced by the monitoring of the delegation...
compared to the monitoring in current methods is presented in Figure 7.

Figure 7: Comparison of monitoring workload between delegation and current methods.

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

PILOT EN-ROUTE ON-LINE RESULTS

The following results are based on twelve delegations.

The pilots always understood the problem when the controller announced the target, and then, always understood the solution proposed by the controller.

In purely technical terms (e.g. flight management, IHM), the delegation is thought “completely feasible”. However when trying to optimise the solution, the delegation became “completely feasible” for only 75% of the cases, and “partially feasible” for 25%. This mainly results from a too basic assistance scheme provided on the CDTI. Typically, for a lateral crossing finding the “optimal” heading requires multiple adjustments, and for a descent crossing the top of descent is not indicated on the CDTI. The delegation is thought compatible with flight management (completely 92%, partially 8%). From a human point of view (e.g. workload, task management, anticipation), the delegation is felt acceptable (totally 58%, enough 42%).

The overall workload resulting from the delegation is between “fair” (62%) and “low” (38%). Compared to current working methods, the workload attached to the communication is between “same” (18%) and “lower” (82%), and the workload attached to the action (monitoring and/or manoeuvre) is between “same” (58%) and “lower” (42%) and slightly increases when trying to optimise the solution. As a consequence, the delegation generally did not affect the concentration on flight management (very little 91%, not at all 9%).

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.

Delegation initialisation

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 7 shows the percentage of the levels of delegations used.

Figure 8: 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 shown in Figure 9, the controllers generally did not hesitate about the level of delegation.

Figure 9: Hesitation for the level of delegation.
As stressed in the outline of the concept, conditions of applicability have been identified and must be respected. 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 10) and the usefulness of the delegation (Figure 11).

Figure 10: Delegation compatibility with current methods.

Figure 10 shows that the delegation was found generally compatible with current methods for a high majority, even with the results of the first session.
Figure 12: Overall workload resulting from the delegation.

Figure 13: Comparison of workload between delegation and current methods.

Again, these results indicate balanced opinions, resulting from the difference between the respect of conditions of applicability. For both sessions, the workload was considered to be low or very low in 63% of the delegations, while this increased to 88% 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.

Delegation monitoring

The workload induced by the monitoring of the delegation compared to the monitoring in current methods is presented in Figure 14.

Figure 14: Comparison of monitoring workload between delegation and current methods.

For the cases where conditions of applicability were respected, 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.

PILOT ETMA ON-LINE RESULTS

The following results are based on nineteen delegations.

As for en-route, the pilots understood the problem and the solution proposed by the controller. In purely technical terms, the delegation is generally thought “partially” feasible and sometimes “scarcely” (completely 16%, partially 68%, scarcely 11%, unfeasible 5%). Similarly to the en-route, this results from a too basic CDTI, but also from the non respect of applicability conditions (see controller’s part): a target aircraft much lower in altitude (e.g. 6,000ft) has a too low ground speed, requiring finally heading manoeuvres for the subject aircraft to maintain distance. As a consequence, the delegation is thought compatible with flight management and is felt acceptable, except for those situations (Compatible: completely 70%, partially 20%, not really 10%; Acceptable: totally 28%, enough 67%, barely 6%).

Compared to en-route results, the overall workload resulting from the delegation increases (44% are “high” or “very high”). Compared to current working methods, the workload attached to the communication remains similar as for en-route. However, the workload attached to the action (monitoring and/or manoeuvre) increases (higher 59%, same 41%), and may affect the concentration of flight management (very much 26%, fairly 63%, very little 11%). Although results concern few pilots, a trend appears indicating that the resulting workload may be higher for sequencing operations than for crossing, and the impact on flying activities is a key issue that requires thorough investigation.

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).

**CONCLUSION**

The EACAC study presented investigates 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 in managed airspace for two classes of application: crossing and passing in en-route, and sequencing in Terminal Manoeuvring Area. One of the two major constraints driving the study relates to human acceptability. The constraint is to respect roles and working methods of controllers and pilots, to enable incremental practice and progressive confidence. For that purpose, EACAC relies on two key points discussed: limited delegation, and flexible use of delegation.

At this stage, 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”, and could reduce workload. 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. It would also provide flexibility to use the method under different traffic conditions, airspace constraints, and controller’s practice level. However, it has been highlighted and observed that the conditions of applicability of the method must be respected, otherwise it could worsen the situations, resulting in an increase of workload and communication.

The next step of the study will therefore be a “quantitative” experiment with the objective of evaluating expected gains of the method. These are mainly an increase in capacity through a reduction of controller workload, together with the improvement of safety and flight efficiency.

ACKNOWLEDGEMENTS

The authors wish to thank P. Renaud, A. Signamarcheix, D. Bradley, J. McCormak, C. de la Torre Cavey, A. Bossu, J. Ertzgaard, F. Loubiers, E. Gerard and C. Sheehan for their active involvement in the experiments presented in this paper and their numerous insightful comments.

REFERENCES