Evaluation of delegation of sequencing operations to the flight crew from a controller perspective – Preliminary results

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ABSTRACT

A simulation has been carried out to evaluate the delegation of sequencing operations to the flight crew from a controller perspective. The airspace simulated was a part of the Paris terminal area, which is one of the busiest in Europe. Six controllers from different European countries participated during two weeks (one week dedicated to sequencing operations, one for en-route that are not discussed here). For the controller, the expected gains mainly rely on a workload reduction that was estimated through the number of instructions given. An important decrease in the number of instructions was obtained with delegation. An initial estimation of the efficiency variation was made through the record of time, distance and fuel consumption. A slight decrease emerges that was also suggested graphically on flown trajectories. A second session is planned that will investigate the monitoring aspects typically through detailed objective workload measurements.

INTRODUCTION

Enhancing air traffic capacity while providing safety improvements constitutes the major challenge facing Air Traffic Management (ATM). However, the growth forecasts for air traffic in Europe and in the United States over the next fifteen years suggest that solely improving the ground component of ATM might not be sufficient to achieve the required capacity at appropriate safety levels. The development of a close co-operation between ground and airborne sides might be required to achieve this challenge. The delegation from the controller to the flight crew of some tasks related to separation assurance is proposed to increase controller availability and flight crew situational awareness. Depending on traffic conditions and airspace constraints, this increased availability is expected to provide safety improvements and to be converted into enhanced traffic capacity or flight efficiency. It takes advantage of emerging CNS/ATM technologies in pre-operational state – ADS-B or TIS-B [4] – along with additional avionics such as a Cockpit Display of Traffic Information (CDTI) [5] or an Airborne Separation Assurance System (ASAS).

The delegation of separation assurance is envisaged for en-route airspace and for terminal areas. For aircraft within an arrival stream in a terminal area, the delegation could consist in tasking the flight crew to determine and perform the necessary speed adjustments so as to maintain a given separation to the lead aircraft. A series of studies dating back to the beginning of the 80s aimed at capturing the essence of in-trail following in terminal areas, from system dynamics and pilot perspectives [1,2,6,7]. Later, merging operations have also been investigated [2]. These studies carried out analytical works and simulations using mathematical models, and pilot-in-the-loop experiments with cockpit simulators. The feasibility of a self-spacing technique in term of dynamics was demonstrated: the separation can be accurately maintained by pilots from cruise to final approach fix, and no instability tendency occurs in strings of aircraft. However, an increase of workload in the cockpit clearly appears thus raising the general issue of identifying the best trade-off between controller and pilot workload. As an initial step to address this issue, the task repartition between controllers and pilots has to be defined and the overall outcomes – benefits? – have to be evaluated.

From a controller perspective, one of the main issues arising by the delegation is the capability to maintain an adequate mental picture of the traffic with delegated aircraft. A pragmatic approach was chosen that starts from the analogy of visual clearances. More precisely, the task repartition relies on two key elements: a limited...
delegation in which the controller leaves no more than implementation tasks to the pilot, and a flexible use of delegation allowing to select the level of task delegated between monitoring up to implementation. This form of delegation has been defined both for sequencing applications in terminal areas, and for crossing and passing applications in en-route airspace [8]. A series of simulations has been carried out to evaluate the expected benefits with a focus on the ground side. The airspace simulated is a part of the Paris terminal area which is one of the busiest in Europe. Six controllers from different European countries participated during two weeks.

The article is organised as follows: the two next sections outline the main principles of this form of delegation and describe the procedures. The two following sections describe the simulation characteristics and present the preliminary results on sequencing applications.

PRINCIPLES OF DELEGATION

This section presents the key elements of the proposed delegation, and their consequences from controller and pilot point of view. It also briefly outlines the procedures.

KEY ELEMENTS

The key elements can be summarised as follows:

No obligation of use: The delegation is a facility provided to the controller, and each controller has the option to use it or not.

Upon controller initiative: The delegation is always initiated by the controller, who decides to delegate a situation if appropriate and helpful.

Visual clearance analogy: The delegation is applicable for situations involving two aircraft. One aircraft – denoted subject – receives the delegation with respect to another one – denoted target.

Limited delegation: The delegation is limited to the tasks of monitoring and implementation of a solution.

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

One parameter delegated: In addition to a limited delegation, for the tasks that may require manoeuvring actions only one (exceptionally two) flight parameter is delegated at a time.

CONSEQUENCES

No change in roles: Situation analysis, identification of problems, e.g. conflict detection, definition of solutions, and decision of delegation remain within role and responsibility of the controller.

The controller keeps the initiative and overall authority on situation management. The core roles and working methods of controllers and pilots remain unchanged.

Same working practices: The delegation can – and must – be used in conjunction with current working practice. The delegation is considered as a new type of ATC instruction. It does not impact on controller’s decision-making.

No change of responsibility: The delegation does not impose any change of responsibility between controllers and pilots. The delegation can be considered as a new instruction. The controller is responsible for providing an appropriate instruction that will ensure the separation and which is acceptable (flyable) by the pilot. The pilot is responsible for following this instruction.

Predictability maintained: Furthermore, the limited delegation being restricted by the delegation of only one parameter at a time, and using appropriate pilot reports, this should allow the controller to anticipate pilot future actions and to predict future aircraft trajectories as today.

Flexibility: The flexible use of delegation would provide flexibility to use the delegation under different conditions such as traffic density, airspace constraints, and practice level. It would also enable a gradual confidence building in the delegation. Indeed, these levels reflect increased use in practice. Each controller should thus experience his own “trade-off”.

PROCEDURE OVERVIEW

Applicability conditions: Prior to delegating, the controller must make sure that all applicability conditions for the envisaged delegation are respected. The respect of these conditions guarantees that the delegation is safe and beneficial. It should be noted that the higher the delegation level, the more restrictive the applicability conditions are.

Delegation instruction: The delegation uses specific controller instructions to define the task delegated, and pilot reports to mark phase changes and the end of delegation.

Delegation phraseology: All the communications between controller and pilot required by the delegation use radio-telephony, i.e. voice communication. A new phraseology is proposed.
Pilot agreement: The delegation requires the agreement of the pilot of the delegated aircraft. No agreement is required from the pilot of the target aircraft, and no indication of his becoming a target is given.

Three phases: The delegation consists in three different phases:

1. Identification phase in which the controller indicates the target aircraft to the pilot of the delegated aircraft.
2. Instruction of delegation in which the controller specifies the task delegated to the pilot.
3. End of delegation which marks the completion of the task delegated.

These phases are described in the following sections.

Interruption of delegation: The controller can interrupt a delegation at any time. The pilot can interrupt a delegation in case of emergency only.

Transfer to next sector: A pair of target plus delegated aircraft can be transferred to the next sector without needing to cancel the delegation.

Additional instruction: During a delegation, the controller can give an additional instruction without cancelling the delegation if the instruction is compatible, i.e. if the flight parameter modified by the instruction (e.g. heading) does not affect the parameter delegated (e.g. speed). This is particularly envisaged for “direct-to” or “descent” for in-trail following.

Anticipation: There must be enough anticipation to set up the delegation process, specifically for highest levels of delegation.

Task sharing: For the delegation aspects, a task sharing between planning controller and tactical controller is proposed: the planning controller will identify the delegable situations, i.e. delegated aircraft, target aircraft and level of delegation. This task sharing follows the trend emerging in current practices where the planning is preparing the analysis of the traffic and conflict detection for the tactical controller.

Technical assumption: For some applications, the trajectory of the target aircraft must be predictable on board the delegated aircraft. Aircraft receives flight state information (position and velocity) of the surrounding traffic through ADS-B or TIS-B. However, it is not assumed at present stage, that intent information such as trajectory is received. For that reason, for those applications, it will be required that the target aircraft is flying straight ahead.

APPLICATIONS

Two classes of application are considered:

- Crossing and passing applications in en-route airspace. Three levels of delegation are proposed corresponding to reporting, maintaining the separation, and providing the separation (Table 1).
- Sequencing operations – merging and in-trail following – in extended Terminal Manoeuvring Area (TMA). Three levels of delegation are proposed corresponding to reporting, maintaining the separation, and resuming then maintaining the separation (Table 2).

<table>
<thead>
<tr>
<th>Airspace</th>
<th>En-route</th>
<th>Crossing and passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delegation level</td>
<td>Lateral</td>
<td>Vertical</td>
</tr>
<tr>
<td>Report</td>
<td>Report clear of target</td>
<td>Report clear of target</td>
</tr>
<tr>
<td>Maintain separation</td>
<td>Resume navigation</td>
<td>Resume climb</td>
</tr>
<tr>
<td>Provide separation</td>
<td>Pass behind</td>
<td>Pass below / above</td>
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Table 1. Crossing and passing applications.

<table>
<thead>
<tr>
<th>Airspace</th>
<th>Extended TMA</th>
<th>Sequencing</th>
<th>Merging</th>
</tr>
</thead>
<tbody>
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<td>Merging</td>
<td></td>
</tr>
<tr>
<td>Report</td>
<td>Report in-trail distance *</td>
<td>Report merging distance</td>
<td></td>
</tr>
<tr>
<td>Maintain separation</td>
<td>Remain behind</td>
<td>Merge behind</td>
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<tr>
<td>Resume then maintain separation</td>
<td>Resume then remain behind</td>
<td>Resume then merge behind</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Sequencing applications. *Not available.

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1 Since the delegation is considered as a new ATC instruction, it could also be envisaged that a delegation cannot be refused, except for serious reasons due to emergency situations or on-board failure.
PROCEDURES FOR SEQUENCING OPERATIONS

This section will describe the different phases of the delegation:

1. Identification phase in which the controller indicates the target aircraft to the pilot of the delegated aircraft.

2. Instruction of delegation in which the controller specifies the task delegated to the pilot. The instruction will be described for each application.

3. End of delegation which marks the completion of the task delegated.

4. The interruption of delegation which may or may not occur.

In the examples presented, DLH456 is the delegated aircraft, and AFR123 is the target aircraft with 1234 as SSR code.

IDENTIFICATION PHASE

The identification of the target aircraft is the first phase of the delegation procedure. The objective is to enable the pilot to select and visualise the target aircraft on his Cockpit Display of Traffic Information (CDTI), upon controller request. The target aircraft is specified by the controller using an unambiguous identifier. In the following, the SSR code is used as the identifier.

The identification consists in three messages:

1. Controller identification message in which the controller indicates the identifier of the target aircraft. For cross-check purposes, the controller could also position the target, or request the pilot to position it.

2. Pilot readback.

3. Pilot confirmation in which the pilot confirms the identification of the target, and positions the target if requested by the controller.

The readback automatically implies the agreement of the pilot for the forthcoming delegation. If the pilot decides — for any reason — to refuse the delegation, he must say so instead of the readback.

Phraseology: Two variants are proposed: either the controller positions the target or requests the pilot to position it (cross check assured by the pilot). The rejection following identification is also proposed.

Identification with positioning by the controller:

Controller: "DLH456, select target 1234, (3 o’clock / right to left / 30 Nm / 1000ft above)"

Pilot: "Selecting target 1234, DLH456"

After pilot selection and identification on the CDTI:

Pilot: "Target 1234 identified, DLH456"

INSTRUCTION OF DELEGATION

The instruction of delegation is the second phase of the delegation procedure. The objective is to specify to the pilot the task he has to handle. This task can range from monitoring to implementation of a specified manoeuvre. The instruction of delegation consists in one controller message and requires pilot readback.

Only instructions for sequencing are presented. For each instruction, the following items are presented: a brief description of the application, task repartition between the controller and the pilot, the parameter delegated to the pilot, the applicability conditions, and the phraseology.

REMAIN BEHIND

Description: The two aircraft are flying along the same trajectory in cruise or in descent phase (Figure 1). The desired separation towards the lead aircraft is obtained. (The lead aircraft is the target, and the trailing aircraft is the delegated one.)

Task repartition:

- The controller: indicates the desired separation to be applied.
- The pilot: adjusts speed to maintain the desired separation.

Delegated parameter: Speed.

Applicability conditions: The two aircraft must fly along the same trajectory.

The two aircraft must have compatible performances.

The two aircraft must have compatible speeds at start of delegation and during the delegation period.

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2 To avoid confusion, the callsign of the target aircraft cannot be used as identifier. However since the SSR code will not be available in ADS-B messages, another identifier would be required.
The current separation must not be lower than the desired separation.

**Figure 1.** "Remain behind" scenario. D is the desired separation. (Colour convention applicable for figures 1 to 4: black: actual situation of target aircraft; grey: initial situation of delegated aircraft; dashed: predicted or potential situation; green: controller instruction; blue: delegated instruction.)

**Observations:** To ensure compatible speeds at start of delegation, the controller may need to issue an initial speed instruction either to the target or to the delegated aircraft.

Aircraft should generally be at similar altitude. (This to ensure compatible speeds during delegation.)

The descent clearance or the top of descent instruction should be given to the delegated aircraft at appropriate time. (This to ensure compatible speeds during delegation.)

A heading or a “direct to” instruction can be given to the lead aircraft. In that case, same instruction must be given to the delegated aircraft. (This to ensure that trajectories remain the same.)

This delegation can be applied from the cruise phase down to the Initial or Final Approach Fix. The delegation can start indifferently in cruise or in descent.

This delegation can be used for aircraft having different trajectories after a given point. In that case, the delegation must end at or before that point.

This delegation can be given to chains of aircraft.

**Phraseology:** Two variants are proposed: the end of delegation relying either on the controller or the pilot. Only the variant with end of delegation by the controller is presented:

**Identification phase**

Controller: “DLH456, behind target, remain 15Nm behind, (until further advice)”

Pilot: “Remaining 15Nm behind target, DLH456”

Once the controller decides to end delegation:

Controller: “DLH456, end delegation, speed instruction”

**RESUME THEN REMAIN BEHIND**

**Description:** The two aircraft are flying along the same trajectory in cruise or in descent phase (Figure 2). The desired separation is not obtained, the controller thus has to give a heading instruction.

**Task repartition:**

- The controller: gives a heading instruction to provide the desired separation towards the lead aircraft; Indicates the desired separation to be applied.

- The pilot: figures out and reports when reaching the desired separation, then resumes navigation behind lead aircraft, and then adjusts speed to maintain the desired separation. (This delegation becomes a “Remain behind”.)

**Figure 2.** "Resume then remain behind" scenario.

**Delegated parameter:** Time to manoeuvre, then heading and speed, then speed.

**Applicability conditions:** Identical to “Remain behind” plus: there must be no restricted manoeuvring airspace during the manoeuvring period – resume navigation behind lead aircraft: no potentially interfering aircraft, no danger area proximity.

**Observations:** Identical to “Remain behind”.
Phraseology: Similarly to the “Remain behind”, the end of delegation relying either on the controller or on the pilot, two variants are proposed. Only the first one is presented:

_Identification phase_

Controller: “DLH456, heading instruction then behind target (proceeding direct to WPT), resume 15Nm behind, until further advice”

Pilot: “Heading instruction readback then will resume 15Nm behind target (proceeding to WPT), DLH456”

Once desired separation is 15Nm:

Pilot: “DLH456, 15Nm behind target, resuming behind (to WPT)”

MERGE BEHIND

Description: The two aircraft are flying along merging trajectories in cruise or in descent (Figure 3). The desired separation is obtained at the merging point.

Task repartition:

- The controller: indicates the desired separation to be applied.
- The pilot: adjusts speed to maintain the desired separation at the merging point, then, after passing the merging point, adjusts speed to maintain the current desired separation. (This delegation becomes a “Remain behind”.)

After the merging point, aircraft must fly the same trajectory.

The two aircraft must have compatible performances.

The two aircraft must have compatible speeds at start of delegation and during the delegation period.

Observations: Identical to “Remain behind” plus: in case one of the two aircraft is not flying straight to the merging point, a direct to the merging point must be given.

Phraseology: Similarly to the “Remain behind”, the end of delegation relying either on the controller or on the pilot, two variants are proposed. The first one is:

_Identification phase_

Controller: “DLH456, behind target, merge to WPT to be 15Nm behind”

Pilot: “Merging to WPT to be 15Nm behind target, DLH456”

RESUME THEN MERGE BEHIND

Description: The two aircraft have to fly along same or merging trajectories in cruise or in descent (Figure 4). The desired separation at the merging point is not obtained, the controller thus has to give a heading instruction.

Task repartition:

- The controller: gives a heading instruction to provide the desired separation to the lead aircraft; indicates the desired separation to be applied.
- The pilot: figures out and reports when the predicted separation at the merging point would reach the desired separation, then resumes navigation to the merging point, and then adjusts speed to maintain the desired separation at the merging point. (This becomes a “Merge behind”.)

Delegated parameter: Time to manoeuvre, then heading, then speed.

Applicability conditions: The target aircraft must fly straight to the merging point.

After the merging point, aircraft must fly the same trajectory.

The two aircraft must have compatible performances.

The two aircraft must have compatible speeds at start of delegation and during the delegation period.

Figure 3. “Merge behind” scenario.

Delegated parameter: Speed.

Applicability conditions: The two aircraft must fly straight to the merging point.
There must be no restricted manoeuvring airspace during the manoeuvring period – resumes navigation to the merging point: no potentially interfering aircraft, no danger area proximity.

**Figure 4.** "Resume then merge behind" scenario.

**Observations**: Identical to “Remain behind” plus: in case the target aircraft is not flying straight to the merging point, a direct to the merging point must be given.

**Phraseology**: Similarly to the “Remain behind”, the end of delegation relying either on the controller or on the pilot, two variants are proposed. The first one is:

*Identification phase*

Controller: “DLH456, heading instruction then behind target, merge to WPT to be 15Nm behind”

Pilot: “Heading instruction readback then will merge to WPT to be 15Nm behind target, DLH456”

Once merging distance is 15Nm:

Pilot: “DLH456, merging distance to WPT 15Nm, merging behind target”

**END OF DELEGATION**

The end of delegation corresponds to the completion of the delegated task. Depending on each application, it occurs either upon pilot report or controller instruction. More specifically, the end of delegation is marked:

- For crossing and passing applications, by the “clear of target” report

- For sequencing operations, by the “passing waypoint” report or the controller new instruction (depending on initial instruction of delegation).

**INTERRUPTION OF DELEGATION**

The delegation can be interrupted by the controller at any time and for any reason, e.g. situation more complex than expected, additional traffic.

The delegation can be interrupted by the pilot only in case of emergency, e.g. CDTI failure, meteorological condition degradation such as storm cell encounter.

**DESCRIPTION OF THE SIMULATION**

**BACKGROUND AND OBJECTIVES**

A first small scale real-time experiment took place in June 1999 [8]. The main objective was to collect feedback from controllers and pilots in order to assess the operational feasibility and potential interest of the concept. 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 were qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses. The overall feeling about the method was “promising with a great potential”. This method could allow an increase in controller availability. In addition, the flexible use of delegation would provide the expected flexibility to use the method under different conditions and would also enable a gradual confidence building. It has been observed however that the non respect of the applicability conditions of the method could result in an increase in workload and communication.

The objective of the present larger scale experiment is to validate the concept in a more realistic environment and to evaluate the expected gains from a controller perspective. For the controller, the expected gains mainly rely on a workload reduction that was estimated through the number of instructions given. It should be noticed that the monitoring aspects also impacting on workload were not yet evaluated. (A measurement based on eye-tracking will be performed during the next session in November ’00.) An initial evaluation on the impact on flight efficiency is proposed through the measurement of time, distance, and fuel consumption.

The differences between the ’99 experiment and this one mainly rely on three elements: all aircraft are equipped to receive delegation, two sectors are simulated at a time, and a high density airspace is used.

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3 The interruption by the pilot must be restricted to such situations since the backup intervention for the controller may induce additional workload and stress.
SIMULATION ENVIRONMENT

The simulation was split into two distinct sessions of one week each: one for sequencing applications and one for crossing and passing applications. From a controller perspective and due to the short training period this splitting was thought to minimise risk of confusion in the use of the two classes of application. From an evaluation perspective, this splitting allowed for a separate analysis thus a better understanding of the outcomes for each class.

Two distinct organisations were thus simulated:

- An extended Terminal Manoeuvring Area (TMA) exhibiting sequencing situations from cruise to the Initial Approach Fix (IAF).
- An en-route airspace exhibiting crossing and passing situations.

The simulated airspace was a part of the Paris South East area which was thought to represent a typical high density airspace (Figure 5). Four existing sectors were selected. Two criteria were considered for selection: firstly the sectors should have arrival and overflying flows to be used for both organisations. Secondly, the sectors should be long enough to allow for a significant duration of the delegations. Sectors should also be large enough since anticipation and space are needed to take maximum advantage of the delegation (Typically to set up the delegation process, to give "resume" point without requiring coordination, and to let aircraft manoeuvre). The four sectors were then combined into two measured sectors. The combination was different for each organisation. For extended TMA, the grouping – which is applied in the reality – allowed for a handling of a majority of flights from cruise to IAF by the same sector. Thus, the delegations process could be simulated and analysed during a significant period of time. In addition, direct instructions to IAF that were intensively used specifically for merging applications did not require any coordination.

![Figure 5. Airspace dedicated to sequencing applications. Flights landing at Charles de Gaulle (LFPG) or Le Bourget (LFPB) from the South-East arrive through AR1 and are transferred to Roissy TMA (feed sector) over SUSIN (IAF) at FL80. Flights landing at Orly (LFPO) from the South-East arrive through AO1 and are transferred to Orly TMA (feed sector) over MEL (IAF) at FL70.](image-url)
The two measured sectors plus two feed sectors were simulated at a time. Each measured sector was manned with two controllers: one planning and one tactical. Each feed sector was manned with one controller. For each organisation, each controller was specialised on one measured sector and simulated as tactical controller on this sector: two training exercises plus two half measured exercises. Each measured exercise was simulated twice: once without the use of delegation, once with it. The duration of each measured exercise was two hours. No specific tool was provided to the controllers.

On each sector, the aircraft were handled by two pseudo-pilots. All the aircraft were ASAS equipped and thus capable to receive delegations. When receiving a delegation instruction (via radio-telephony), the pseudo-pilot activated the corresponding function performing automatically the separation assurance.

The traffic samples were derived from two traffic recordings performed in the Paris Area Control Centre covering traffic flow in the morning and in the afternoon on the 13th of October 1999. For the extended TMA organisation, the traffic was mainly composed of arrival flows. The arrival traffic was slightly increased and adjusted to create clusters of up to five aircraft, and to have similar traffic load for both sectors. The sequencing of these clusters could lead to continuous streams of aircraft (Figure 7). The resulting traffic was close to a real high density traffic and validated by a Paris Controller.

**PRELIMINARY RESULTS**

For the following results, a measured period of two hours has been chosen for each exercise starting approximately 15 min after the beginning of the exercise. A total of three exercises (denoted Ex1, Ex2 and Ex3) have been simulated twice: without and with delegation. Ex2 and Ex3 were based on the same traffic sample.

The number of arrival flights and the sector load are indicated below for each sector (Tables 3, 4). The number of arrivals is identical for both sectors. The traffic load was lower for AR due to more overflying traffic in AO. However due to the complexity of the route structure the resulting workload for AR was considered as equivalent to that of AO.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>IAF</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>Stdev</th>
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</thead>
<tbody>
<tr>
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<td>15</td>
<td>6</td>
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</table>

**Table 3. Number of aircraft in sector AO.**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>IAF</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
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<td>5</td>
<td>10</td>
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</table>

**Table 4. Number of aircraft in sector AR.**

The variation of workload with and without delegation is estimated through the number of manoeuvring actions which is listed below (Tables 5, 6). Standard instructions of separation and delegation instructions are indicated by type along with the total number. (The "report merging distance" application was not used and is therefore omitted.)

In order to compare the variation in the number of messages, the number of target selections is also indicated. The transfer instructions have been omitted since transfer to next sector induces the same number of messages with and without delegation.

<table>
<thead>
<tr>
<th>Instruction type</th>
<th>Ex1</th>
<th>Ex2</th>
<th>Ex3</th>
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**Table 5. Instruction number for AO.**

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<th>Ex2</th>
<th>Ex3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading</td>
<td>10</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Direct</td>
<td>12</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Speed</td>
<td>16</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Level</td>
<td>20</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Standard instructions</td>
<td>302</td>
<td>299</td>
<td>299</td>
</tr>
</tbody>
</table>

**Table 6. Instruction number for AR.**
Some differences in the number of instructions can be noticed among exercises but may rely on different techniques of control. However, no significant trend emerges. As discussed previously, sector AR requires apparently more manoeuvring instructions.

The summary of the number of instructions is given in Table 7 and in Figure 6. The most important result is the significant decrease in the number of instructions with delegation (28% for AO, 34% for AR). The major decrease results from the reduction of speed instructions. It should be stressed that the reduction is more important for AR sector requiring more instructions (vectoring and speed). The reduction of instructions is thought to reflect a reduction of the task of control. As a result of the reduction of the manoeuvring actions, particularly speed and heading changes, trajectories becomes more stable (see also Figure 8). Less time-critical “guiding” to maintain separation is necessary.

Concerning the number of messages exchanges (i.e. target selections included), a decrease is also visible (18% for AO and 25% for AR). However, while a reduction of the frequency occupancy was expected and felt by all the controllers, no significant variation has been recorded. Technical problems with the voice recording may explain this result.

An initial estimation of the efficiency variation was made through the record of time, distance and fuel consumption. Total and mean values are indicated below (Tables 8, 9). A slight decrease emerges with delegation from the three parameters. The flight efficiency is also graphically suggested on flown trajectories (Figure 8): with delegation trajectories become straighter.

### Table 7. Summary of instruction number for all exercises (figures in brackets represent standard deviation).

<table>
<thead>
<tr>
<th>Instruction type</th>
<th>AO</th>
<th>AR</th>
<th>AO</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading</td>
<td>51 (5)</td>
<td>74 (29)</td>
<td>17 (4)</td>
<td>35 (11)</td>
</tr>
<tr>
<td>Direct</td>
<td>51 (11)</td>
<td>60 (8)</td>
<td>34 (11)</td>
<td>33 (4)</td>
</tr>
<tr>
<td>Speed</td>
<td>75 (25)</td>
<td>107 (35)</td>
<td>19 (9)</td>
<td>13 (5)</td>
</tr>
<tr>
<td>Level</td>
<td>66 (7)</td>
<td>93 (18)</td>
<td>59 (4)</td>
<td>68 (9)</td>
</tr>
</tbody>
</table>

**Standard instructions**: 243 (40) 333 (57) 129 (13) 149 (18)

<table>
<thead>
<tr>
<th>Instruction type</th>
<th>AO</th>
<th>AR</th>
<th>AO</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>EndDelegation</td>
<td>7 (3)</td>
<td>6 (3)</td>
<td>47 (8)</td>
<td>53 (10)</td>
</tr>
<tr>
<td>Delegation</td>
<td>243</td>
<td>333</td>
<td>175</td>
<td>202</td>
</tr>
<tr>
<td>SelectTarget</td>
<td>39 (4)</td>
<td>47 (7)</td>
<td>8 (3)</td>
<td>9 (7)</td>
</tr>
<tr>
<td>ResumeThenMerge</td>
<td>14 (7)</td>
<td>16 (7)</td>
<td>16 (2)</td>
<td>22 (2)</td>
</tr>
<tr>
<td>ResumeThenRemain</td>
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<td>0 (0)</td>
<td>8 (3)</td>
<td>9 (7)</td>
</tr>
<tr>
<td>Merge</td>
<td>12 (2)</td>
<td>16 (2)</td>
<td>47 (8)</td>
<td>53 (10)</td>
</tr>
<tr>
<td>Delegation</td>
<td>243</td>
<td>333</td>
<td>175</td>
<td>202</td>
</tr>
<tr>
<td>All instructions</td>
<td>243</td>
<td>333</td>
<td>215</td>
<td>249</td>
</tr>
</tbody>
</table>

### Table 8. Total efficiency figures.

<table>
<thead>
<tr>
<th>Ex</th>
<th>Time (h)</th>
<th>Distance (Nm)</th>
<th>Fuel (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34:52:30</td>
<td>13314</td>
<td>838696</td>
</tr>
<tr>
<td>1 ASAS</td>
<td>33:24:35</td>
<td>13026</td>
<td>810361</td>
</tr>
<tr>
<td>2</td>
<td>37:05:55</td>
<td>13329</td>
<td>764981</td>
</tr>
<tr>
<td>2 ASAS</td>
<td>34:28:35</td>
<td>13060</td>
<td>754834</td>
</tr>
<tr>
<td>3</td>
<td>35:42:50</td>
<td>13353</td>
<td>754288</td>
</tr>
<tr>
<td>3 ASAS</td>
<td>33:39:45</td>
<td>13025</td>
<td>737003</td>
</tr>
</tbody>
</table>

### Table 9. Mean efficiency figures.

<table>
<thead>
<tr>
<th>Ex</th>
<th>Time (h)</th>
<th>Distance (Nm)</th>
<th>Fuel (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:22:16</td>
<td>142</td>
<td>8922</td>
</tr>
<tr>
<td>1 ASAS</td>
<td>0:21:20</td>
<td>139</td>
<td>8621</td>
</tr>
<tr>
<td>2</td>
<td>0:23:11</td>
<td>139</td>
<td>7969</td>
</tr>
<tr>
<td>2 ASAS</td>
<td>0:21:33</td>
<td>136</td>
<td>7863</td>
</tr>
<tr>
<td>3</td>
<td>0:22:19</td>
<td>139</td>
<td>7857</td>
</tr>
<tr>
<td>3 ASAS</td>
<td>0:21:02</td>
<td>136</td>
<td>7677</td>
</tr>
</tbody>
</table>

### Figure 6. Summary of instruction number.

### Figure 8. Distance and fuel consumption.

In the scope of evaluating the benefits of the delegation of sequencing operations to the flight crew, a simulation with controllers has been carried out. An existing organisation including two measured sectors with arrival flights was simulated. From a controller perspective, the delegation allows for a significant reduction in the number of instructions given. This is thought to reflect a possible workload reduction. In terms of efficiency, time, distance and fuel consumption are also reduced, and it appears also that trajectories become more stable. In this paper, only raw quantitative results have been presented. Detailed analysis including the controller questionnaires is forthcoming. It should provide more insights in the actual impact of delegation on the controller working methods, in particular modification and/or rescheduling of tasks. A second session is planned for November’00, and the impact of the delegation on the monitoring task will be investigated. A more detailed focus will be put on flight deck issues. The impact of non-nominal situations on delegation will be investigated in future experiments.

### CONCLUSION

In the scope of evaluating the benefits of the delegation of sequencing operations to the flight crew, a simulation with controllers has been carried out. An existing organisation including two measured sectors with arrival flights was simulated. From a controller perspective, the delegation allows for a significant reduction in the number of instructions given. This is thought to reflect a possible workload reduction. In terms of efficiency, time, distance and fuel consumption are also reduced, and it appears also that trajectories become more stable. In this paper, only raw quantitative results have been presented. Detailed analysis including the controller questionnaires is forthcoming. It should provide more insights in the actual impact of delegation on the controller working methods, in particular modification and/or rescheduling of tasks. A second session is planned for November’00, and the impact of the delegation on the monitoring task will be investigated. A more detailed focus will be put on flight deck issues. The impact of non-nominal situations on delegation will be investigated in future experiments.
Figure 7. Example of planned (upper) and flown traffic (lower).
Figure 8. Trajectories without delegation (upper) and with delegation (lower).
ACKNOWLEDGEMENTS

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REFERENCES

The materials used for presentation and training during the simulation are available at www.eurocontrol.fr/projects/freer/index.htm


